JØRGEN LAURITZEN

LEGG-CALVÉ-PERTHES DISEASE

A Comparative Study

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by
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PREFACE

The studies to be reported in this volume were started in 1967 while I was clinical assistant at the Arhus University I am very grateful to Professor E Thomasen of the Orthopaedic Hospital Arhus for having given me access to the patient material from this Ho pital for his interest in my study for help and guidance in its performance

From the very earliest phase I have been in touch with the person in Denmark who knows most about the disease in question Johannes Meyer M D former Head of the Seaside Hospital Refsnæs I owe a debt of deep gratitude to Dr Meyer for the part he has taken in my studies for numerous discu sions oral and in writing through the years and for his never failing and ever vivid interest in the job For access to the files of case notes and X-ray films in the Refsnæs Hospital I am greatly indebted also to its present Head Hans Bohr M D who displayed a constant interest in the progress and results of the study and contributed by instructive discussions Thanks are due moreover to the staff of the Refsnæs Hospital for extensive obligingness and help as well as for hospitality during my visits to collect data

The investigations were continued while I was working in the Orthopaedic Department run by the Society and Home for the Disabled in Odense Thanks are due to my chiefs in that Department K Harry ørensen M D and A Randløv for their interest and for the access to that part of the Thomas caliper series which had been treated in Odense The normal material too was collected in Odense

During my appointment as research assistant to the Anatomy Department of the Odense University I had ideal working conditions for combining and writing up all the data I am thankful to Professor F Bierring Head of the Department who also took an intense interest in the investigation of the vascularization of child hips which I carried out during that period My thanks are due also

to members of the Department staff who rendered help in various ways and took part in the studies

For careful typing of the book I would like to thank Jonna Madsen medical secretary The statistical calculations were per formed by H K Kvist M Sc , to whom I am indebted for incredibly speedy help in a part of the study which I had no possibilitie of solving myself

Last but not least I want to thank my wife Hanne for her great practical help at many late hours, in recording the numerou data on punch cards (Karlo Hansen system) and for her enormous patience during all the years that this study took so much of the time which I ought to have spent with my family It is therefore a great pleasure to dedicate this book to my wife and children

Århus January 1975

Jørgen Lauritzen

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OBJECT OF THE STUDY

I To review the literature with the main emphasis on

(a) what has been published regarding Legg-Calvé-Perthes disease since 1960

(b) ascertaining the long-term prognosis of the disease,

(c) being able to discuss aetiological hypotheses in the light of other types of epiphyseal necroses affecting the femoral head

II To describe an out-patient treatment method by which the patients are relieved of weightbearing sitting in a wheel chair and

(a) investigate how this therapeutic method can be practised in relation to the patient s home situation

(b) analyse the primary healing results

III To investigate the true value of analysing the result by measurements on X-ray films

(a) by assessing the accuracy of the measurement

(b) by comparing the results of two different investigators by cross-control measuring

IV To assess by means of prognostically relevant grouping a very large case material with a view to the influence of the following factors upon the result

(a) patient s sex

(b) age at institution of treatment

(c) radiological stage at institution of treatment

(d) degree of epiphyseal changes on the X-ray film

(e) degree of relief from weightbearing assessed for different methods of treatment

CHAPTER 1

INTRODUCTION ON LEGG-CALVÉ-PERTHES DISEASE

PRIMARY HISTORY OF THE DISEASE

Discovery

In June 1909 a young surgeon Arthur T Legg read a paper to the American Orthopedic Association about 5 children suffering from a special hip disease On 17 2 1910 he published his findings accompanied by X-ray films of four of the patients His description and especially his discussion of the disease entity was extremely lucid and logical He suggested traumatic avascular epiphyseal necrosis as a possible explanation of the changes observed in children aged 5 - 8 years who limped but presented scanty clinical changes

On 10 7 1910 the Frenchman Jacques Calvé gave a thorough clinical and radiological description of the same disease He had found 10 patients among 500 having hip pain The age range was from 3½ to 10 years Two of the patients were siblings Calvé realized that he was dealing with a disease sui generis

In October of the same year the German professor Georg Perthes (1910) described the same disease in 6 patients He interpreted it as juvenile osteoarthritis and did not recognize until 3 years later in a more detailed paper on 21 patients (Perthes 1913) in which he referred to Calvé that this was a separate disease entity of familial occurrence

As early as 1909 the Swede Henning Waldenstrom had described the same disease but interpreted it as a special type of juvenile tuberculosis of the hip

Name

The disease did not at first receive any official name Michelsen (1914) in Denmark suggested that as a suitable honour the disease be provisionally called Calvé-Perthes disease and as such it is still commonly known in Denmark presumably because Møller (1926) passed this name on Michelsen did not refer to Legg whose paper he probably did not know possibly because in those times Danish medical science was more oriented towards literature in German

than in English This is perhaps the explanation why Legg s name has never got further than on a level with the other two Recent linguistic rationalization especially in Anglo-Saxon literature has shown a tendency to omit two of the names calling the condition merely *Perthes disease* Thus the honour which Michelsen wanted to confer has eventually fallen to the wrong man

In searching the literature a number of guide words have to be employed apart from the names of Legg Calvé and Perthes as the libraries and the great international journals have not yet standardized their index term for the disease Most often it is still recorded under its original designation osteochondritis juvenilis coxae

The present author has chosen the designation Legg-Calvé-Perthes disease (LCPD)

INCIDENCE

The disease is fairly rare but there is a marked racial difference (Goff 1954) apparently with a preponderance in the white race In Denmark Mose (1964) found an incidence of 0 9 - 1 0 per 1000 live born infants Molloy & MacMahon (1966) in a study among the population of Massachusetts found an incidence in the white population of 0 816 per 1000 distributed by 1 35 in 1000 boys and 0 27 in 1000 girls Among Broder s (1953) 102 patients only 7 were Negroes although the population served by the hospital was mainly of Negro origin However there has been no real incidence study in races other than the white

CLINICAL FEATURES:

The most important clinical aspects of the disease had been mentioned in the very first reports The first major study (Sundt) saw the light of day in 1920 and since that time there have been no important additions The disease arises during childhood between the 2nd and 12th year of life but with an age peak from the 6th to the 8th year Boys are affected about four times as often as girls the right and left hip with almost equal frequency but in about 10% both hips are involved There is a pronounced familial accumulation and traumas are often adduced as having initiated the symptoms

By far the most outstanding sign is a limp which however does not seem to trouble the child much Occasionally the patients

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either (1) local storing of calcium (2) compression of necrotic parts of spongy bone or (3) newformation of bone on dead trabeculae

After relative sclerosis and a subchondral translucent line (Fig 1) the epiphysis starts flattening anteriorly This is followed by increasing general flattening with true epiphyseal sclerosis This appearance (Fig 2) should no longer be interpreted as the initial stage



Fig 1 Early stage Distin t suochondral line in the anterior part of the epiphysis Relative sclerosis in the remaind r of t e epiphysis (Case 2)



pi sis c de sed a d la te ed Epi seal line wide a d tra slu e t t ards e metap ysis Greatly adva ed s a e (Case 41)

complain of pain in the hip thigh or knee they tire quickly and often find it difficult to keep up with mates of their own age when running and playing The symptoms are so far from alarming, that often a long time may elapse before a doctor is consulted

On physical examination the main finding is restricted mobility in the hip joint especially in abduction and internal rotation There is also mild atrophy of the femoral muscles

RADIOLOGY

A child with a limp should always have his hips examined by radiography which is the best method for establishing the diagnosis The disease runs a characteristic and thoroughly investigated radiological course which Waldenstrom (1923) divided into several stages It is important to know the early X-ray signs and in his review of the disease Møller (1924) pointed out the value of Lauenstein's projection as well as the anteroposterior view The classical radiographic findings have most recently been summed up in a major review by Edgren (1965) Waldenstrom (1934) mentioned as an important early sign in the anteroposterior view an increased width of joint space medially from the head of the femur to the so-called Kohler tear drop and on the Lauenstein film a subchondral linear translucency in the anterior part of the epiphysis Eyring et al (1965) confirmed that the width of the joint space medially is increased by more than 1 mm as compared with the good side in 70% of early LCPD patients whereas 96% of 1000 normal hips showed a difference of less than 1 mm As stated by Caffey (1968) the widened joint space is due to a diminished epiphysis

An increased density of the femoral head epiphysis has been mentioned as a characteristic sign during the initial stage In densitometric studies Bohr (1971) found that initially the radiodensity of the epiphysis was the same on both sides The epiphyseal sclerosis is only relative due to decalcification of the surrounding bony tissue Brailsford (1948) related the relatively increased density of avascular necrotic bone to lacking decalcification The surrounding decalcification is presumably due to increased blood flow in the region as Bessler (1969) found by autoradiography and scintigraphy that this is the usual reaction of living bone to necrotic foci As causes of truly increased sclerosis he mentioned

The fragmentation which always occurs may comprise a varying part of the epiphysis Ponseti & Cotton (1961) divided it into three degrees with different rate of course and different therapeutic result A change in structure throughout the epiphysis was found in only one sixth of their patients The severity of epiphyseal and metaphyseal changes is parallel At a time which may be extremely difficult to fix with accuracy the X-ray appearances show signs of increased reconstruction of the bony structure In a radiographic study of 200 patients Simril (1961) maintained that he had seen no case in which the fragmentation increased anew once the improvement in epiphyseal structure had begun The structure gradually improves until it has returned to normal at the time of primary healing At that time the head has attained a shape which may vary between severely flattened irregular and normal spherical shape This shape is largely maintained ever after The long-term prognosis of the disease depends upon whether or not the head attains spherical shape In rare cases the healing leaves osteochondritis dissecans but according to Ratliff (1967) this is of no clinical importance judging by two cases followed through 30 years However Morris & M Gibbon (1962) have reported one such case in which the osteochondritis fragment loosened

LABORATORY FINDINGS

In the literature on LCPD from the first 30-40 years the various authors did not succeed in demonstrating any laboratory findings that were abnormal or could otherwise be called definitely characteristic of LCPD More recently Schonenberger et al (1962) and Hirthe & M hlbach (1966) have found slightly increased excretion of taurine in a number of LCPD patients in studies of the urinary excretion of amino acids but this has not yet led to any diagnostic or therapeutic consequences

Otto (1968) considered this as compressed broken trabeculae At this stage there are often changes in the epiphyseal line which is more irregular and wider than on the good side There appear also more distinct metaphyseal changes with a more pronounced decalcification in the area adjoining the epiphyseal line possibly with cyst-like translucencies Gill (1940) even considered these metaphyseal changes as being primary and the epiphyseal changes secondary

After or perhaps simultaneously with the condensation and flattening of the epiphysis its structure starts breaking up into the so-called fragmentation (Fig 3) Even though the film now apparently shows an irregularly flattened epiphysis the shape of the femoral head is in fact not much changed Arthrography using iodized contrast medium (Jonsater 1953 and Katz 1968) injection of CO_2 into the joint (Koch 1969) as well as operations on the joint (*Haythorn* 1949 *Cathro & Kirkaldy-Willis* 1963 Larsen & Reimann 1973) have shown the cartilage-lined head to be considerably closer to spherical shape than the shadow of the bone might lead one to assume By measurements on arthrographies Axer & Schiller (1972), however found only one of 17 heads to be spherical the remainder being flattened laterally and the majority also anteriorly



Fig 3 Example of subtotal fragmentation (Case 83)

position during which its entire anterior half is uncovered



Fig 4 Situation of the femoral head in the acetabulum when the hip joint is extended The anterolateral area where LCPD starts is marked



Fig 5 The femoral head enters the acetabulum when the hip is flexed The anterolateral area is almost totally covered (arrow)

From the transverse acetabular ligament the ligament of the femoral head courses to the fovea This ligament and the fat pad in the acetabular fossa are intracapsular but extrasynovial The synovial capsule extends from the cartilaginous border on the head to the acetabular lip along the inside of the fibrous capsule This forms a synovial fold around the femoral neck most pronounced medially and anteriorly where the capsular attachment is farthest from the cartilaginous border

GROWTH OF THE PROXIMAL END OF THE FEMUR

The intracapsular part of the upper femoral end consists of the epiphysis and the metaphysis which are separated by the epiphyseal cartilage and a small part of the diaphysis The epiphyseal ossification centre forms when the infants are 4 - 8 months of age The epiphyseal ossification centre grows predominantly along the periphery at the transition to the articular cartilage in the basal

CHAPTER 2

ANATOMY OF THE HIP JOINT DURING CHILDHOOD

TOPOGRAPHY

LCPD affects that part of the upper femoral end which is situated within the capsule of the hip joint It therefore seem appropriate to describe the anatomy of the hip joint during childnood in some detail

The femoral head constitutes about two-thirds of a sphere lined with hyaline cartilage except at the site of the fovea which contains fibrous connective tissue The articular surface in the acetabulum is a large segment of a hemispherical cup in which the incisura acetabuli is not lined with cartilage but filled with fatty tissue The transverse acetabular ligament spans the incisu and the acetabular lip supplements the articular socket the rest o the way

The fibrous capsule extends from the external aspect of the acetabular lip and the transverse ligament to the femoral neck where it is solidly anchored in the orbicular zone which is highly developed during childhood The capsule attaches loosely to the bone anteriorly and medially at the site of the intertrochanteric line posteriorly and laterally at the middle of the femoral neck The capsule fibres and the fortifying iliofemoral ischiofemoral and pubofemoral capsular ligaments run a tortuous course in pronation

In direct relation to the capsule the iliopsoas muscle pronate antero-medially whereas the external obturator muscle courses late rally across the posterior aspect of the joint capsule Both musc les effect external rotation of the joint moreover the iliopsoas flexes and the external obturator adduces

When the hip joint is extended the capsule ligaments and muscles tighten and the tightening effect is increased in internal rotation and abduction When the joint is flexed all these structu res relax completely as they do also to some degree in adduction and external rotation On flexion in the joint the femoral head is moreover much better covered by the acetabulum than in an extended

and course in a subsynovial situation up along the neck as retinacular vessels After giving off branches to the metaphysis the vessels penetrate the edge of the epiphyseal cartilage and enter the epiphysis On the anterior aspect of the joint similar branches derived from the lateral femoral circumflex artery course as rami nutricii capitis anteriores along the neck in a subsynovial situation to the anterior aspect of the metaphysis and epiphysis From the acetabular artery a branch the arteria ligamenti capitis femoris accompanies the ligament to the fovea

Before the epiphyseal centre has been formed the head consists of a cartilaginous sphere on a short broad neck A few vessels mainly from the distal aspect enter this sphere The process of ossification begins around these vessels in the centre of the sphere Gradually as the epiphyseal centre grows these afferent vessels assume a more peripheral position through the epiphyseal cartilage During the next couple of years the epiphysis is supplied almost equally from the three sets of branches proximal-lateral distal-medial and anterior



Fig 6 Injection of Mic ophil R and clearing by the method of Spalteholz in the normal femoral head of a child aged 3 years 10 months viewed from the posterior aspect The epiphyseal vessels fill from 3 proximal nutrient branches and one distal nutrient branch Foveal vessels superiorly on t e right

part of which calcium is deposited, and osteogenesis takes place beneath this site Throughout childhood the epiphyseal plate makes the epiphysis an isolated bony island surrounded by cartilage except in the foveal area

Metaphyseal growth takes place from the basal part of the epiphyseal plate along the lateral edge of the femoral neck, and from the basal aspect of the epiphyseal plate of the greater trochanter Growth in the upper end of the femur has been studied in rat foetuses (Lutken 1947) and in pigs and rabbits (Salenius & Videman 1970)

At birth the femoral neck is very short The head is in a valgus position and anteverted During childhood the inclination as well as declination angles diminish most rapidly during the first 2 years of life (Glogowski 1962 Shands & Steele 1958) The latter authors found the neck to be more anteverted in girls than in boys Among 34 LCPD patients they found only 6 to be anteverted by more than 10° above average This agrees with Katz (1968) but is at variance with Craig et al (1963) who found LCPD to occur always in hips with considerably increased anteversion The shape and inclination of the pelvis also shows sex differences during childhood apart from being dependent on genetic factors (Gardner et al 1969)

VASCULAR SUPPLY OF THE HIP JOINT IN CHILDREN

The studies of Wolcott (1943) Tucker (1949) Trueta (1957) Harty (1953 1966) Hipp (1962) Crock (1967) Mussbichler (1970) and Lauritzen (1974) seem to have established the vascular supply of the femoral head and the variations in the course of the vessels during childhood

The deep branch of the medial femoral circumflex artery runs behind the femoral neck between the quadratus femoris and the external obturator muscles ending laterally on the neck where it perforates the capsular attachment as rami nutricii capitis proximalis coursing deep to the synovial membrane up along the neck as retinacular vessels These vessels penetrate the cartilage at the junction of the epiphyseal plate and cartilage surface whereupon they enter the epiphysis after having given off branches to the metaphysis

From the deep branch vessels in the form of rami nutricii capitis distalis perforate the capsular attachment postero-medially

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According to Trueta (1959 1960) these anastomoses are more constant in Negro children than in the white race At the age of 4 - 6 years first the anterior and then the distal retinacular arteries stop running into the epiphysis Until the epiphyseal cartilage starts closing and thus no longer forms a barrier to anastomoses between the metaphyseal and the epiphyseal vascular network the epiphysis is increasingly dependent on a normal function of the deep branch of the medial circumflex femoral artery and its final twigs

The distribution of the vessels in the epiphysis especially during the critical age interval does not appear to have been the subject of thorough studies However it has been demonstrated by Trueta & Morgan Trueta & Little and Trueta & Amato (1960) in histological electron microscopic and experimental studies on the vascular contribution to osteogenesis in animals that a tortuous vascular network forms in the basal part of the epiphysis between the condensation line and the growth cartilage The cartilage is nourished by the vessels in the epiphysis From the metaphysis vessels force their way densely and brush-like in between the cartilage columns and endochondral osteogenesis is dependent upon this vascularization Wolcott (1943) published photographs taken from the lateral aspect and judging by these photos the vascular network appears to be less dense in the anterior part of the epiphysis an appearance which was confirmed by Lauritzen (1974) The venous discharge does not seem to have been studied in any detail in children but the veins apparently accompany the arteries

INNERVATION OF THE HIP JOINT

This has been studied by Gardner (1948) Larochelle (1949) Kaiser (1949) and Wertheimer (1952), and may be summed up as follows

The joint receives branches from the obturator nerve from the sacral plexus and from the femoral nerve The obturator branch appears to be the most important one As a rule it departs before the bifurcation of the obturator nerve in the obturator canal or a short distance after the bifurcation and if so most often from the anterior branch The entrance of the nerves into the joint is medially through the external obturator muscle and the pubocapsular ligament or deep to the transverse acetabular ligament The obturator branch seems to constitute the main innervation of the anterior two-thirds of the joint Incidentally the obturator nerve supplies the



Fig 7 Same specimen as in Fig 6 *viewed from the anterior* aspect where 5 thin anterior nutrient branches enter the epiphysis

Throughout childhood, the arteria ligamenti capitis femoris supplies in the main the ligament the connective tissue in the fovea and the synovial membrane around the ligament but also has delicate anastomoses with the epiphyseal vascular network However these anastomoses are probably not of decisive importance in epiphyseal nutrition (Schulz 1971)



Fig 8 Same technique as in Fig 6 in a normal child aged 6 year, 3 months The vessels in the fovea are seen floating above the epiphysis with one small anastomosis entering it (arrow)

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adductor muscles, and the branch to the external obturator muscle departs either from the main stem or from the posterior branch The obturator nerve often sends sensory branches down to the medial aspect of the knee joint

Innervation of the posterior aspect of the joint is from the sacral plexus or from the sciatic nerve as a rule *via* the musculo-articular nerve which innervates also the quadratus femoris muscle, often the inferior gemellus muscle and sometimes the internal obturator muscle Some uncertainty prevails concerning the innervation from the femoral nerve In a special study of this component Wertheimer found that it never reached the joint itself only the vessels It might be imagined that the autonomic nerves to the joint would course this way corresponding to the vascular supply by the branches of the femoral artery whereas the cerebro-spinal nerves would accompany the other two nerve stems

CHAPTER 3

MICROSCOPIC FINDINGS IN EPIPHYSEAL NECROSIS IN THE FEMORAL HEAD

PATHOLOGY IN LCPD

Only a few authors have had the occasion to study the morphological changes in the entire affected femoral head Zemansky (1928) reviewed 11 cases and added one of his own At that time most studies were based upon femoral heads removed by operation but a few were from autopsies Since then Gall & Bennett (1942) and Dolmann & Bell (1973) have described one autopsy case each and Jensen & Lauritzen (1974) two autopsy cases Since resection of the femoral head as a treatment has been abandoned long ago such studies of the total affected head will be extremely rare in the future and can be based solely on deaths among children suffering from active LCPD



Fig 9 Cross section of the left femoral head in LCPD The patient died at the age of 4 years 10 months when the disease was in the phase of healing

The investigations have shown consistently that the articular cartilage is normal or perhaps shows faint signs of degeneration

basally The epiphysis is the seat of severe or total marrow necrosis but otherwise consists of a mixture of areas showing necrotic bone amply vascularized granulation tissue, and cartilage islets New-formed bone may be observed as creeping apposition In some cases the epiphyseal plate is totally degenerated, in others near-normal The vessels appear to be normal

These findings have been confirmed by a number of other authors who have taken biopsies *most often when drilling through* the femoral neck The most comprehensive and most systematic study on biopsies is the one by Jonsater (1953) who linked the radiological stages up with histological differences In the early stages he found like Haythorn (1949) that the necrotic bony tissue might have broken down and got compressed In sites where the bony necrosis was adjacent to the cartilage border the basal part of the cartilage may be degenerated At the stage of fragmentation the tissue was more vital showing incipient bone formation which increased through the stage of repair According to Exner (1968) the histological appearances differ widely from those in posttraumatic *epiphyseal necroses Mattner (1968) observed bone formation as* "creeping apposition even in the early stage and this has been observed also by Larsen & Reimann (1973) By a radiological study Munzenberg (1968) demonstrated that the structure of collagen in the epiphysis is normal in LCPD

ANIMAL CONDITIONS SIMILAR TO LCPD

Thomasen (1939), studying the head of the humerus in 1482 pig bones found 4% with grossly flattened head a wrinkled surface of the articular cartilage and microscopic changes in part of the epiphysis exactly similar to those in LCPD

In dogs Moltzen-Nielsen (1938) has found epiphyseal necrosis in the femoral head with skeletal as well as partial cartilaginous necrosis This finding has been confirmed by Hulth et al (1962) while Ljunggren (1967) found this process to start in miniature dogs as increased endosteal growth of bone whereby the trabeculae *thickened prior to incipient necrosis* She believed that the aetiology was hormonal but did not rule out (Ljunggren 1969) that the blood supply might play a certain role According to Ljunggren Rutt & v *Schmoller (1969) tried to induce the changes* by administering chorionic gonadotropins but did not succeed when using rabbits

or large dogs as experimental animals

From a study of gorilla skeletons Taylor et al (1955) deduced that these animals might also suffer from an LCPD-like disease

EXPERIME TAL EPIPHYSEAL NECROS"S IN ANIMALS

Many authors have performed animal experiments and studied the behavior of the epiphyses in connection with avascular ischaemia

Bentzon (19 6) and Randløv-Madsen (1950) injecting alcohol around the femoral neck in rabbits believed they had induced LCPD-like epiphyseal changes Miltner & Hu (1933) did not obtain this result until they supplemented the alcohol injection with removal of the periosteum around the femoral neck in their experimental animals

Harris & Hobson (1956) after traumatic epiphysiolysis on the femoral heads of rabbits very soon observed necrosis in the epiphysis which collapsed before regeneration was completed They found only mild changes in the articular cartilage The same experiment on the epiphyseal disc of the distal end of the radiu (Dale & Harris 1958) does not induce epiphyseal necrosis as it does not tear all the vessels to this epiphysis but it causes the same transient interruption of endochondral ossification from the epiphyseal cartilage

Following traumatic dislocation of rabbit hips Bohr et al (1965 and 1968) studied the results by radiology microradiography and microscopy by the conventional technique as well as by fluorescence after labelling with tetracycline They observed changes very similar to LCPD int al temporary invasion of vessels from the metaphysis through the epiphyseal cartilage Such vascular invasion into an avascular epiphysis was observed by Young (1966) in an experiment in which he used the epiphysis of the metatarsal head in rabbit young Medgyesi (19"1) after pedicled revascularization of the sawn-off femoral head from the trochanter or a muscle found the epiphyseal cartilage plate to form an absolute barrier to vascular invasion If the vascularized pedicle was brought into direct contact with the epiphysis a slow process of re-ossification followed upon the primary necrosis but bone formation occurred last in the most remote parts of the epiphysis The articular cartilage was not described

Slätis & Rokkanen (1966) induced epiphyseal necrosis by sub-

capital osteotomy on rabbits They observed collapse of trabeculae during the first stages and also observed the regeneration to be progressing slowly from the metaphysis and outwards The cartilage and the most adjacent part of the bone did not undergo necrosis, and this site was the only one to retain the tetracycline labelling one week later a sign of nutrition from the synovial fluid Lemoine (1957) demonstrated that the vascular supply of the femoral-head epiphysis in rabbits is somewhat different from that in man However the differences do not appear to be too marked for rabbit experiments to reproduce the human changes quite well

Salter (1966) induced necrosis of the femoral head in pigs by ligation around the neck Bone growth was arrested but not cartilage growth Thus it appears that the articular cartilage remains vital due to some nutrition received from the synovial fluid Indeed Mankin (1962) found that tritium-labelled thymidine injected into rabbit knee joints was recovered partly in the most superficial layer of the cartilage and partly at the junction to bone at the two sites where cartilage activity is at a maximum That the articular cartilage is also dependent upon the vascularization in the underlying bone was demonstrated by McKibbin & Holdsworth (1966) in an elegant experiment on young lambs In their experiment the basal part of the cartilage and the osteogenesis proved to be dependent especially upon the vascularization of the bone also related to time but the tissue was reactivated after revascularization In a rabbit experiment Young (1966) demonstrated how the epiphyseal cartilage plate depends upon epiphyseal vascularization whereas osteogenesis on the metaphyseal side depends upon the metaphyseal vessels

CHAPTER 4

RELATION TO OTHER DISEASES

CONGENITAL DISLOCATION OF THE HIP

It is beyond doubt that epiphyseal changes of the type seen in LCPD will occur in a considerable number of those children in whom congenital dislocation of the hip is not diagnosed and treated at birth and who are presented for reduction later This was described by Legg as early as 1927 Massie (1951) found these LCPD-like changes to be far more common in boys although dislocations occur more often in girls Meyer (1964) pointed out that the epiphyseal changes in congenital dislocation of the hip belong to the type which he calls epiphyseal dysplasia of the femoral head He found a familial relation between these two conditions and LCPD

As to the frequency of such changes there is great disagreement Dooley (1963) has reported 50% Limbers (1965) 16 - 20% and Illyés only 6 7% In a series of 627 patients treated for congenital dysplasia or dislocation of the hip Tonnis & Kuhlmann (1969) found the frequency among all 1254 hips to increase appreciably with age Epiphyseal necrosis occurred in 10 3% of those treated during the 1st year of life in 47 2% treated during the second year and in 62 3% treated during the 3rd year Regardless of age only one-fifth developed changes of a severity which involved distinct flattening of the epiphysis The increasing frequency with age among all the hips indicates a relationship to the abduction treatment given rather than to the dysplastic hip and is compatible with a vascular explanation based on the anatomical relations This has been confirmed by the angiographic studies of Nicholson et al (1954)

In German literature these epiphyseal changes are often termed Luxationsperthes int al by Schulz (1971) who found them to be far more common following open reduction plus derotation osteotomy than following open reduction alone The patients most liable to these changes were those treated conservatively before the operation

TRANSIENT SYNOVITIS IN THE HIP JOINT

Among 46 patients with transient synovitis in the hip joint Spock (1959) reported subsequent LCPD changes in 3 Hardinge (1970)

found no aetiological explanation of transient synovitis in the hip Like LCPD this disease is most common among boys aged 5 - 9 years and both sides are equally often affected The complaints are scanty but the limitation of motion more diffuse According to Valderama (1963) Adams (1963) and Gledhill & McIntyre (1969) there seems to be no relationship between this benign short-lasting disease and LCPD Emr (1966) on the other hand believes there is Calculating the epiphyseal index on both hips he found a number of LCPD patients to have inferior epiphyses This applied particularly to the youngest patients in whom the condition is most often bilateral In this constitutionally hereditary group he feels that synovitis is a factor in the development of LCPD the flatter epiphysis being more apt to cause obstruction of the vessels In consequence he treats patients with synovitis and flat epiphyses with non-weightbearing for 3 months In contradistinction to this group he found that LCPD children with a history of trauma were older and always had normally developed epiphyses when the disease started, and in these cases the condition was never bilateral In this way he tried to unravel the aetiological factors in LCPD

Stillman (1966) felt that LCPD and osteochondritis dissecans were of the same genesis LCPD arising in cases of a specific multifacetted constitutional disturbance occasionally with an inherited familial predisposition and elicited by trauma or stress to the hip

DELAYED SKELETAL MATURATION

The oft-mentioned constitutional factor has been interpreted as delayed growth and skeletal maturation in relation to chronological age Haythorn (1949) Mau & Schmitt (1960) Ralston (1961) Ponseti & Cotton (1961) as well as Fischer (1972) have reported that in LCPD children bone age is delayed by a year or two Molloy & MacMahon (1967) found LCPD patients to have a lower birth weight than a control group

ENDOCHONDRAL DYSOSTOSES

Owing to the familial tendency and the localization in the epiphysis it is reasonable to imagine that LCPD is related to the various diseases involving a disturbance of endochondral osteogenesis Mau (1958) imagined that such disturbances might possibly constitute the endogenous component of LCPD the vessels to the

epiphysis being more easily obstructed when the cartilage was of poor quality The epiphyses of the hip are nearly always involved in Morquio s disease (Robinow 1958) and in what Fairbank (1945) called multiple epiphyseal dysplasia The similarities and especially the differences between these dysplasias and LCPD have been discussed by Weinberg et al (1960) Rubin (1965) and Kozlowski & Lippska (1967) Jacobs (1968) pointed out that long-lasting non weightbearing is of no value in multiple epiphyseal dysplasia as it is in LCPD

Trias & Ray (1963) have described a boy with LCPD who one year later developed aseptic necrosis of both radial heads Studying the X-ray films of 120 patients with LCPD Hubner (1968) found a higher than normal frequency of delayed synostosis between the ramus ischii and the ramus inferior ossis pubis (van Neck s disease) This he interpreted as a sign that LCPD was due to a generalized disturbance of ossification

OTHER AVASCULAR EPIPHYSEAL NECROSES IN THE FEMORAL HEAD

Atraumatic

Gaucher s disease may be accompanied by epiphyseal necroses int al in the femoral head Arkin & Schein (1948) believed that this was due to perivascular accumulation of Gaucher cells and according to Katz (1967) the condition may recur after primary treatment and improvement something which does not happen in LCPD

In Negro children in whom LCPD is extremely rare epiphyseal necrosis may occur in the presence of sickle-cell anaemia Golding et al (1959) found no metaphyseal changes in these cases Chung & Ralston (1969) reported an LCPD-like course in 6 out of 13 patients The cause of the necrosis is said to be microthrombi of the abnormal blood cells elicited by reduced oxygen tension

An entirely new phenomenon is aseptic epiphyseal necrosis following renal transplantations This was found by Cruess et al (1968) in 10 out of 27 patients who survived longer than 6 months In these cases too the femoral head epiphysis was the one most often involved The articular cartilage was normal That these necroses are attributable to the cortisone medication seems to be more evident now that Harrington et al (1971) have demonstrated that their occurence is dependent upon the dose of cortisone Rodegerdts (1969) found necrosis of the femoral head in a 12-year-

old girl who had been on long-term cortisone thepapy for ulcerative colitis By angiography he demonstrated occlusion of the distal vessels to the head as well as narrowing of the deep branch He presumed that cortisone altered the coagulability of the blood Markheim (1949) has reported the case of a patient with unilateral LCPD who 2½ years later exhibited epiphysiolysis in the contralateral femoral head The same applies to Case 121 of the present material

Traumatic

Traumatic dislocation of the hip in children is sometimes followed by necrosis of the femoral head This has been reported by Quist Hansen (1945) in 1 out of 8, by Piggot (1961) in 1 out of 9 and also by Haliburton et al (1961) in one case in which the condition soon returned to normal Glass & Powell (1961) have reported that among the 25 cases on record from 1927 to 1958 6 developed necrosis In their own series of 47 cases 4 developed necrosis and 3 degenerative changes in the joint Hipp (1969) found a much higher frequency viz 5 total and one partial necrosis out of 10 dislocations and among 40 children with fracture of the femoral neck he found 17 to develop total and 3 partial necrosis By arteriography he demonstrated that sometimes the vessels to the epiphysis merely get obstructed but open up again if reduction is carried out immediately

Although a fracture of the femoral neck is extremely uncommon in children, there have been many reports Nielsen (1938) described 3 Carrell & Carrell (1941) 12, Allende & Lezama (1951) 8 Ingram & Bachynski (1953) 24 Durbin (1959) 3 and McDougall (1961) 24 Ratliff (1962) had seen 19 and reviewed 52 treated elsewhere so that his material comprises 71 patients 30 of whom developed necrosis Lam (1971) found only 17% with necrosis among his 75 cases Summing up it may be said that necrosis occurs very often when the fracture is transcervical or subcapital and when it is displaced The necrosis may involve the entire proximal fragment in that event it leads to total epiphyseal collapse and the end result will be poor However partial epiphyseal necrosis or isolated metaphyseal necrosis may occur and in such cases the prognosis is considerably better The course and result may be explained simply on the basis of the vascular supply to the upper end of the femur

In epiphyseolysis without trauma epiphyseal necrosis is also

common but as a rule it is partial Rutner (1954) Lowe (1961 and 1970) and Maurer & Larsen (1970) agree that cartilaginous necrosis is a more common finding than bony necrosis and of much more prognostic importance Salter & Harris (1963) as well as Ratliff (1968) found that traumatic epiphyseolysis in the femoral head was a very serious disease with a high risk of total epiphyseal necrosis and permanent deformation of the joint

OTHER DISEASES NOT AFFECTING THE FEMORAL HEAD

From 178 LCPD patients and 89 control patients Katz (1959) deduced that LCPD bore no definite relation to occult spina bifida

Catterall et al (1971) made a systematic study of 282 patients and their families They found a surprisingly high frequency of various urinary tract anomalies plus 8 times the expected number of inguinal hernias among the 2 9 boys They suggested that anomaly of the development of the vessels in the hip might be an aetiological factor when combined with changes in the urogenital primordia In cases with developmental anomalies following thalidomide Stainsby & Quibell (1967) found LCPD changes in two such children However one of them had previously been treated with a Dennis-Browne splint for subluxation of the hip

AETIOLOGICAL THEORY

Owing to the infinitesimal information about the pathological changes in other forms of epiphyseal necroses in children deductions have to be made from the clinical and radiological prognosis of the various diseases compared with the findings in adults

Merle d Aubigné (1964) as well as Patterson et al (1964) found the articular cartilage to be normal in idiopathic necrosis of he femoral head in adults This is found also in cortisone-induced necrosis and is an invariable finding in LCPD The necrosis is primarily of a subchondral localization In medial fractures of the femoral neck in adults Hult (1961) found cartilaginous necrosis whene er there was bony necrosis and in 13 out of 21 angiographed patients Müssbichler (1970) found that the lateral epiphyseal artery (ram s nutricius capitis proximalis) never filled when filling of the deep branch was delayed This finding confirms those of Lange & Hipp (1960) who demonstrated also that normally the lateral epi- physeal artery may be followed by angiography 1 cm into the epiphysis

In his comprehensive arteriographic study Hipp (1962) found in patients with LCPD narrowing or total occlusion of the deep branch behind the middle of the femoral neck

All findings indicate that the ischaemia which causes LCPD is considerably more moderate than it would be if the vessels to the epiphysis were occluded by trauma or by a thrombus There must be a question of a much briefer obstruction of the vessels, as also hinted by Trueta & de Lima (1959) As causes they suggested either synovial inflammation or an effect of the small external rotators of the hip

In my opinion the explanation lies on the most peripheral part of the deep branch Normally this artery runs just distal to the tendon of the external obturator muscle, curving superficially to the tendon towards the lateral part of the femoral neck perforating the capsule and proceeding subsynovially to the edge of the epiphysis where it penetrates the cartilage as several branches, just at the junction of the epiphyseal and articular cartilage before inflecting about 60° and entering the epiphysis (Fig 6 & 7, pp 11 & 12)

If this artery has a genetically determined abnormal course, and perhaps runs deep to the tendon of the external obturator it will be squeezed against the femoral neck when the hip is in - sion, and even more when it is in abduction and internal rotation On the other hand flexion adduction and external rotation leave free flow in the artery The same motor pattern that tightens the tendon will tighten the joint capsule and thus will compress the artery in its course between the capsular fibres Sex differences in the inclination and width of the pelvis may be operative The arteries laterally on the femoral neck are well hidden and protected from traumas but yet they may be injured by the acetabular margin during maximum abduction in the joint

Due to periodical obstruction necrotization of the epiphysis will set in The severity of this necrosis depends upon whether other arteries supplying the epiphysis according to age and racial factors are able to reduce the ischaemia The highly undifferentiated bone-marrow cells necrotize first and later this will affect endochondral osteogenesis which takes place mainly in a subchondral situation An already inhibited or reduced endochondral osteogenesis is particularly liable to the changes The osteogenetic changes

occur first in the anterior part of the epiphysis which is the most peripheral one in its vascular network Thereafter the necrosis will spread to already formed bony trabeculae The nutrition of the epiphyseal cartilage plate will also be disturbed but endochondral ossification will continue in the entire metaphysis later even at an increased rate because of the subsequent hyperaemia As the most resistant tissue the articular cartilage will remain vital int al because of the nutrition it receives from the synovial fluid An adduction-external rotation spasm in the muscles of the hip is the most expedient direct defence of the organism as this reduces the tension on the deep branch This spasm may give rise to mild pain apart from of course entailing a limp Flexion of the hip secures the best possible blood flow in the arteries supplying the epiphysis

CHAPTER 5

TREATMENT OF LCPD

NON-WEIGHTBEARING

In view of the uncertain aetiology of LCPD practically all authors suggest and recommend treatment on an empirical basis

During the first 20 years after the disease had been described no special therapeutic principles were suggested The literature from these years in fact gives an impression merely of pleasure at recognizing that the disease was not infectious in particular not tuberculous but a kind of inevitable juvenile destruction of the hip running a self-limiting course which caused the patient surprisingly little complaints even years after healing (Sundt 1920 Waldenstrom 1923 Legg 1927) From the mid-30 s interest in treatment by long-term non-weightbearing increased and it was realized that thereby a considerably larger number obtained better primary healing of the femoral head (Danforth 1934 Eyre Brook 1936) This has been confirmed by all subsequent studies

Since that time, any discussion has concerned the best method for non-weightbearing the duration of non-weightbearing and whether it might perhaps be supplemented by som other form of treat ment that could further improve the results or at least shorten the course

The most reliable method for relieving the diseased femoral head from pressure is to put the patient to bed with fixed legs under constant observation The strictness with which this was carr ed through in som clinics is apparent from Pike s (1950) analysis of 59 children who had been tied to a frame in a hospital bed around the clock for periods ranging from 1 to 5 years By this mana excellent radiological results had been obtained

Ferguson (1954) opposed such very rigid fixation In his opinion it was essential that the hip could retain its mobility throughout but it had to be spared any muscle traction This he attained by traction in the longitudinal direction of the leg with out stating any time limits Katz who most recently analysed his results in 1967 still recommends bed rest + traction which he fc to afford the most favourable results This view is fully shared by

Meyer (1969) who reported no psychological strain on the children from a long s a/ in hospital Larbert (1968) on the other hand who derived his experience from teaching long-term orthopaedic paedia ric pa ients came up against certain psychological and paedagogic difficulties Thompson & Bassett s experiments (1970) leave doubt as to the importance of treating the femoral head by total relief from weightbearing By a histological study these authors found progressive signs of degeneration in the articular cartilage as well as in the underlying bone in rabbit knees treated by non weightbearing

Harrison et al (1966 1969) felt it was of great importance that the femoral head be fully contained within the acetabulum during the period of non-weightbearing as the acetabulum was supposed to mould the head into spherical shape In 1966 they found the best results after bed rest with the legs fixed in so-called broomstick plaster In 1969 however they had changed their views towards a preference for ambulatory treatment during which the leg was fixed around the clock for about 2 years in a specially designed leather brace Tachdjian & Jouett (1968) described a similar enormous bandage for ambulatory use In an equally drastic manner fixation of the hip has been consistently used for 17 years by Imhauser (1970) as an ambulatory method He fixed with plaster from mid chest down to and including the affected foot with the hip in 30° abduction 30° flexion and 30° external rotation Petrie & Bitenc (1971) have also used a large plaster bandage with the hips in 45° abduction and in $5 - 10^{\circ}$ internal rotation through 19 months ambulatory treatment but the cast was changed every 3 or 4 months Dethloff (1966) was content with plaster in inversion for a month or two whereupon he changed to a gentler ambulatory treatment

Most authors who recommend ambulatory treatment have u ed gentler methods In 1947 Snyder described a sling for use in combination with ordinary crutches This method has been used by Evans & Lloyd-Roberts (1958) and also partially in the present material

By various forms of walk ng appliances the children are rendered independent of crutches Hansbrough et al (1959) used at Taylor splint but most often ischial weight-bearing braces are used e g the Thomas caliper which has been extensively used in Denmark at least previously The results have been reported by Reimann (1961) and Mose (1964) and patie ts treated by this means are also includ-

ed in the present material These walking appliances keep the hip in extension which is not a particularly favourable position Katz (1971) pointed out the importance of the moulding effect of the acetabulum upon the femoral head, when the latter is completely contained within the socket Therefore Cochhiarella et al (1972) designed a removable brace which permits walking with the legs in 45° abduction and 20° internal rotation The patients are allowed only one hour daily without the bandage

No author seems to have dwelt on the time at which non-weightbearing should be started Apparently it is a presupposition that it should start as soon as the diagnosis has been established The problem is however for how long the non-weightbearing is to be continued, and this must rest on a medical estimate Herndon & Heyman (1952) reported a mean period of 17 2 months, discontinued when regeneration was well under way Wilk (1965) recommended non-weightbearing for 3 - 4 years until the head has healed completely but the necessity is doubted by Cumming (1967) Pappas (1967) took his guidance from the time when the surface contour had been re-formed According to Goff (1959 1962) short-lasting relief from weightbearing gives equally good results as long-lasting and he is now less afraid of allowing weightbearing at an early juncture He has reduced his average non-weightbearing period to 9 months as compared with 19 months previously

SUPPLEMENTARY TREATMENT

Mere relief from weightbearing has to many seemed rather poor as the only therapeutic principle In the course of time many other treatments of a more direct nature have been suggested as supplementary measures mainly with the object of making the process run a more rapid course so that the treatment period could be shortened

During the past decade several suggestions have been advanced Goff (1955) had given the preliminary statement that apparently he could shorten the course and the non-weightbearing period by administering aureomycin In 1965 he confirmed in a double-blind study on 54 patients that tetracycline could significantly accelerate skeletal growth so much that he obtained quicker healing and moreover better results No one seems to have had any inclination to test his ideas which do not appear to have gained ground elsewhere The mechanism is perhaps by way of adrenocortical hormones a route

which has been tried also by Kristensen (1963) by a supplement of anabolic steroid Ponseti & Cotton (1961) treated 22 patients with triiodothyronine On comparison with 44 patients not thus treated they found no effect of the hormone therapy This only confirms Gill s (1943) study in which he found no signs of impaired thyroid function in 20 LCPD patients

Altav & Geimer (1967) tried to supplement by vasodilator agents in 14 patients and claimed that this accelerated healing Berényi (1969) also wanted hyperaemia in the hip which he obtained locally by injecting liver oil into the joint in 74 patients He observed no side effects and felt that this could shorten the course by a year or two

OPERATIVE TREATME T

In the course of time there have been numerous attempts at improving the results or hastening the course by operations on the hip

Prior to 1930 operation was used only sporadically but Bozsan (932) recommended the use of drilling through the femoral neck, perforating the epiphyseal disc In 1934 he described his technique in more detail but pointed out the risk of premature epiphyseal closure This method was used in 8 of the patients studied by Levy & Girard (1942)

Ferguson & Howorth (1934) reported that since 1928 they had used drilling up through the anterior aspect of the neck to the epiphysis in 15 patients They had observed a surprisingly rapid healing which set in at once and afforded excellent results Howorth was still optimistic in 1948 but now felt that the operation was most favourable during the stage of fragmentation or of healing Steele (1943) used a considerably more radical method removing the ne ro ic bone in the epiphysis by drilling through the neck and inserting fresh spongiosa instead Thereby he obtained accelerated healing but gave no further details concerning the shape of the head or the end result The same operative procedure was used by Cathro & Kirkaldy-Willis (1963) who stated that they had observed several cases in which the epiphyseal plate regenerated after the operation Camargo (1957) advocated a method of drilling a long plug of bone from the neck but only jus up to the epiphyseal cartilage which was not injured The plug was then inserted upside

down After this procedure he observed quicker healing, which he explained as a possibly improved vascularization in the area However the method had afforded good results only when performed during the initial stage Such plugging with bone seems to have been used in Germany where Neurath (1968) found a number of cases with total epiphysiodesis and poor shape of the head Hirthe (1965) would not recommend the insertion of a bone plug after drilling whereas Löwe (1969) preferred inserting a wedge of bone instead of nailing with a metal nail after having tried both

Svobodova & Svoboda (1967) compared the results in 105 patients treated by drilling with 700 treated conservatively They would not recommend drilling despite a good effect in one-third Chapchal (1965) too in his textbook opposed drilling nailing and bone plugging He had used all methods, but had not observed better results or quicker healing than in conservative treatment On the other hand, the operations involved a considerable risk of injuries resulting in poorer function of the joint Instead, he recommended derotation osteotomy on the femur

In the course of time it has been noticed that some femoral heads flatten laterally during the period of fragmentation and remain lopsided In consequence Garceau (1964) operated upon 21 such hips chiselling off the lateral prominent part of the epiphysis so that the remainder of the head could again fit into the acetabulum He followed 7 of the operated patients 3 of whom developed myositis ossificans Regerettably he did not mention how he avoided injuring the arteries supplying the epiphysis The method does not seem recommendable

Craig et al (1963) were among the first to use derotation osteotomy on the femur or pelvic osteotomies as they found LCPD to occur always in hips with appreciable anteversion an average of 45° and believed that the aetiology was pressure necrosis on the anterior part of the head The intention was to give the head a better position in the acetabulum At the same time they observed a considerably shortened healing period Rinaldi (1964) also used correcting osteotomies subtrochanteric or intertrochanteric in 5 patients who were healing in an unfavourable varus deformity He obtained a rapid healing On the same motivation Axer (1965) operated upon 12 patients In an objective evaluation of the result he found the best results in patients who had early operation and among the youngest patients This is of course not surprising

Pipino & Simone (1967) also performed correcting osteotomies when this seemed needed but also did partial osteotomy without correction in mild cases Within both categories they observed a marked acceleration of the healing rate In their opinion this was due to changes in the local blood flow transosseous phlebography demonstrating an altered direction of the venous discharge

Osteotomy seems to be gaining ground as a therapeutic method, as it is being realized that it tends to accelerate healing This has been observed also by Farkas (1969) Girod (1969) and Taussig & Hériprêt (1969) However it still remains an open question how the operation exerts a favourable effect upon the rate of the disease process if it does and whether it can possibly afford better healing results The tendency is towards believing that it is the osseous hyperaemia resulting from the osteotomy which is disseminated all the way into the epiphysis where it increases osteogenesis However Haluzicky (1965) claims to have seen an increased rate of healing and absence of the fragmentation stage in 15 patients treated by the muscle detachment operation of Voss Such a procedure would not be expected to cause hyperaemia of the bone for more than at most a couple of days According to Sommerville (1971) it had not yet been established that healing could be accelerated by osteotomy but he nevertheless used correction osteotomy to obtain a better position of the head in the acetabulum The same therapeutic principle was used by Jani (1971) Haraldsson (1973) and Laurent (1973) Jani stated that the operation shortened the leg by a maximum of 1 5 cm Hördegen & Witt (1971) after varisation osteotomy in 50 cases discussed the approach on the basis of 20 of these patients At all events they were adherents of a better containment within the acetabulum and the modelling effect of the varisation but they obtained good results only when the operation was performed during the initial stage Postoperatively after healing of the osteotomy they used short-lasting non-weightbearing in a Thomas caliper or allowed full weightbearing at once Salter (1966) has performed corrections of the joint by pelvic osteotomy

Operative treatment by osteotomy usually with varisation or derotation has gained ground in many countries during the past 0 years Still too little is known about the detailed results both with respect to the rate of healing and the appearance of the head after healing Axer & Schiller (1973) have reported the results in their 34 patients but still there has not been any

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analysis of a sufficiently large operated material assessed with due regard to the various factors which influence the result apart from the treatment

Personally I doubt whether sufficiently good results are obtainable by operation without non-weightbearing at all ages and in my opinion it is still of interest to know the value of the various treatments by non-weightbearing

CHAPTER 6

LONG-TERM PROGNOSIS OF LCPD

Before the disease was described as a separate entity in 1910 Maydl (1897) and v Brunn (1903) among others had described osteoarthritis of the hip in older children In his first paper from 1910 Perthe referred to these authors and indeed he too looked upon the disease as juvenile osteoarthr tis However there is nothing to indicate t at the cases of o teoarthritis described before his time were due to LCPD

Even though the X-ray film showed deformity of the joint with certain characteristics reminiscent of osteoarthritis often as early as the time of primary healing in untreated cases it was soon realized that the clinical appearances were not like those in true osteoarthritis

Waldenstrom (1923) had followed 40 patients during the period after 1907 Out of 45 untreated hips only 4 had re urned to normal He observed that function was surprisingly good even in the oldest patients despite deformity of the hip

Legg (1927) following 40 patients for more than 10 years found that neither the cases showing the most favourable healing in mushroom shape nor the poorest ones with cap shape were incapacitated

As the end result in 20 cases followed for periods of from 3 to 28 years mean 8 5 years Slocum (1941) found osteoarthritis in an astoundingly small number of cases Among the patients with oval femoral heads none had osteoarthritis

Sundt (1949) in the follow-up on 137 patients with 153 LCPD hips 10 52 years after the onset of the disease observed radiological signs of osteoarthritis in 65 hips Amo g the 11 spherical heads none showed osteoarthritis but this increased in frequency with increasing deformity being present in 16 of 56 oval in 41 of 78 cyli drical in and all 8 of angular shape Only 17 patients had a reduced working capacity; 9 of them had severe complaints disabling in 4

Mindell & Shermann (1951) followed 72 pa ients with 78 hips for 40 years They concluded that despite severe radiological changes there might be only mild or no symptoms in young adults but that the symptoms increased with advancing age

After more than 25 years follow-up Relbo (1953) found

osteoarthritis in 60% of 52 patients who had received only syntomatic treatment or none These cases occurred in the deformed hips none in those attaining spherical shape

Ratliff (1956) reported the late results for 50 hips 11 - 30 years after the onset mean follow-up period 17 years Only 5 hips exhibited major osteoarthritis with pain although the X-ray films showed a good result with a normal or slightly flattened head in only 20 of the cases Thirteen years later (Ratliff 1967) 34 of the patients were seen again when the follow-up period averaged 30 years range 25 - 40 years 80% of the patients were free of pain and fully active, although only 14 hips were radiologically satisfactory Only a few showed clinical or radiological exacerbation during the intervening 13 years Two had been in hospital, one to undergo hip fusion On the basis of this material the author concluded that a good result during childhood had largely kept the patients free of pain and in a good functional state at least up to the age of 40

Evans (1958) reported the findings in 52 patients seen 10 - 36 years mean 16 years after the onset He found osteoarthritis only in the 16 with angular irregular heads, not in 15 spherical and 21 elliptic with smooth surface

Wansbrough et al (1959) studying 129 patients followed for 5 - 26 years admitted that as a rule the patients did very well despite considerable deformity of the head until they reached middle age Only 5 were occupationally handicapped and hip fusion had been needed in only 1 case

Trueta (1960) briefly stated that a follow-up on 125 LCPD patients at an adult age to detect osteoarthritis showed this to be present only in deformed and incongruent joints In a study on the aetiopathology of osteoarthritis of the hip Trueta (1963) found that its onset presupposes primary degeneration of cartilage e g due to insufficient subchondral blood supply This may be seen in incongruent hip joints Trueta wrote There is no reason to believe that developmental joint diseases such as the osteochondritis of the Legg-Perthes type affects the joint in later days other than by the joint incongruency it may cause with its repercussion on the nutrition of the joint cartilage The same opinion was expressed by Axhausen as early as 1923 who found that osteoarthritis might arise in two ways: The chondral type in which the cartilage is primarily degenerated which it is not in LCPD and the osseous type

in which epiphyseal necrosis gives rise to irregular healing of the head and thereby an incongruous joint end which may wear the opposing cartilage and osteoarthritis is the result

Danielsson & Hernborg (1965) saw 35 patients more than 20 years average 33 years, after the onset They point out that the series is too small to justify final conclusions but osteoarthritis was more severe and more common in patients with a high degree of deformity Among their 14 patients with no or little deformity of the head none had pain limitation of function or major radiological changes and all had normal mobility On the other hand they found all their 7 patients with pain all 4 with restricted funtion 12 of 15 with limitation of motion and 9 of 11 with major radiological osteoarthritic changes among the 13 patients with the most severe deformity of the hip

Eaton (1967) followed 100 LCPD hips in 88 consecutive patients mean follow-up period 19 years range 10 - 43 years The 61 hips with a radius variation of less than 3 mm measured by a template according to the principle of Goff had satisfactory function although only 7 of the heads were entirely spherical 7 of the 88 patients wanted operative treatment because of severe complaints 6 of these patients had strenuous physical outdoor occupations

Sanders & Mac Ewen (1969) followed 40 of the patients from their material for more than 10 years All who healed with a radius variation of less than 2 mm were still doing well without complaints and only a few of those with poorer healing had complaints

An average of 36 3 years after the onset of the disease Gower & Johnston (1971) studied 36 patients clinically and radiologically The mean age was then 44 6 years Most of these patients had been treated in a plaster cast The most typical clinical findings were slight shortening and a slight limp but little pain and negligible limitation of function The symptoms did not increase with age or length of follow up period All 6 heads assessed as being spherical had good mobility and a normal width of the joint space whereas all 9 patients with moderate or severe osteoarthritis had flattened heads *In a study of 475 arthroplasties for osteoarthritis of the hip only 4 exhibited the sequelae of LCPD* It is maintained also by Strange (1965) that among patients with osteoarthritis of the hip only a very few show X-ray appearances reminiscent of previous LCPD

According to these reports on the long term follow-up of patients

with a history of LCPD it seems justified to assume that femoral heads which are spherical and have a radius variation within the range of 2 mm encountered in normal series run no risk of developing osteoarthritis at least for 30 - 40 years and presumably onwards It is indeed surprising that no complaints or instances of osteoarthritis have been reported in cases healing with a spherical caput magnum which according to Ferguson & Howorth (1935) involves a potential risk of osteoarthritis because of the altered weight-bearing conditions

Similarly the prognosis seems to be amazingly good in cases where the surface of the head is smooth and congruent with the acetabulum, although the radius variation exceeds 2 mm These ovoid shapes make for moderate limitation of motion but rarely pain and apparently such patients remain capable of heavy unskilled labour walking as well as standing Whether the result will be maintained beyond a follow-up period of 30 - 40 years remains to be seen

In cases where the head has healed in an irregular angular shape and is thus incongruent with the acetabulum there is little doubt that the prognosis is poor although Francillion (1967) reckons them only as possibly pre-osteoarthritic Among such patients we find the few who have already been treated by operation or who want such treatment for their secondary hip complaints All patients with functional or occupational problems and troublesome pain belong to this type

CHAPTER 7

PRESENT MATERIAL

DEFINITION AND DESCRIPTION OF THE 4 SERIES

The present study is retrospective and comprises a total of 475 patients in whom LCPD had been diagnosed and who had been treated by various forms of non weightbearing under the supervision of hospital units

Table 1

TOTAL MATERIAL

		Method of treatment			
		Wheel-chair	Bed rest	Traction in bed	Thomas caliper
Total patients	475	141	96	156	82
Unilateral	388	114	79	113	82
Bilateral	58	21	13	24	0
Excluded	29	6	4	19	0

THE WHEELCHAIR SERIES consists of 141 consecutive patients started on the treatment at the Orthopaedic Hospital Arhus during the 8 year period 1 1 1957 to 31 12 1964 The treatment was quite predominantly ambulatory the patients being treated by non-weightbearing sitting in a wheelchair This series is the primary one as the results of this therapeutic method have not previously been analysed

For the sake of comparison and in order to gather a sufficiently large number of patients for an overall assessment of LCPD another 3 series were included in the material

THE BED REST SERIES consists of the 96 consecutive cases started on treatment at the Seaside Hospital Refsnæs during the 5 year period 1 1 1953 to 31 12 1957 This series is identical with part of Mose s material (1964) and has already been included in another study (Meyer 1966) These patients were treated predominantly by long-lasting bed rest in hospital followed by an ambulatory period with Snyder s sling and crutches in some cases on an out-

patient basis

THE TRACTION IN BED SERIES consists of 156 cases also consecutive started on treatment at the Seaside Hospital Refsnæs during the subsequent 6-year period 1 1 1958 to 31 12 1963 The former half of this series is included in Meyer's study from 1966 In the great majority of these cases the strict bed rest was supplemented by intermittent, light traction As a rule the traction periods lasted for 6 weeks with 1 - 1½ kg traction on each leg by rubber foam fixation and the hip joints in slight flexion and abduction alternating with a 2-week bed rest without traction After 6 or 7 periods of traction the patients were kept in bed for 4 - 6 months Thereafter they were ambulatory with Snyder's sling as in the above series but most often they were kept in hospital throughout

THE THOMAS CALIPER SERIES consists of 82 patients treated predominantly by ambulatory non-weightbearing in a Thomas caliper The first 59 patients were treated in the Orthopaedic Hospital Arhus during the period 1949 - 1955 and the last 23 at the Orthopaedic Clinic Odense during the period 1952 - 1963, before both units changed to wheelchair therapy During these two periods the therapeutic and especially the follow-up principles were not adhered to quite as systematically as later To avoid operating with a large consecutive material and having to exclude many cases I selected this series The criterion for selection was that X-ray films were still available for the entire duration of the disease as this made it possible to compare the course and result with those in the other series

From the first 3 series 29 patients were excluded and are not considered in any part of the analysis The motivation for these exclusions is apparent from the patient lists From the wheelchair series 6 patients were excluded (Cases 25 73 77 105 121 and 140) Two had a history of congenital dislocation of the hip one developed epiphysiolysis of the femoral head later one has developed rheumatoid arthritis with severe changes in the hip joints one died of congenital heart disease and one received no treatment at all as the disease was not detected until at an advanced stage when she was 13 years of age From the two Refsnæs series I excluded 4 and 19 patients respectively These exclusions were performed in accordance with the two previous investigators to render the results of the present analysis comparable with theirs

Among the remaining 446 patients the main emphasis was laid

on analysing the 388 patients who had unilateral LCPD In all four series these cases were recorded as regards sex side affected age at institution of treatment duration of symptoms nature and duration of treatment The entire radiological course was analysed Particular attention was given to the subjective as well as objective staging at the institution of treatment Moreover the result after healing was assessed objectively by studying the shape of the femoral head and its inner structure in both views and comparing the findings with the healthy femoral head

In addition the wheelchair series was subjected to further analyses of various kinds which will be reported below

In 58 patients the disease was bilateral Regardless of whether both sides were affected at the same time or at an interval and regardless of the severity of the current radiological changes they are considered bilateral These cases were not analysed quite as thoroughly especially not with respect to an accurate grading of the X-ray appearances They will be discussed in Chapter 12

NO WEIGHTBEARI G TREATMENT IN A WHEELCHAIR

In 1955 Professor E Thomasen of the Orthopaedic Hospital Arhus conceived the idea that patients with bilateral LCPD could be protected from weightbearing by out-patient treatment in a wheelchair The method was described in 1969 (Thomasen) This idea was based on the wish for non-weightbearing with the hip in fle ed position in order thereby to reduce the compressive action the muscle traction upon the femoral head and at the same time p a e it well into the acetabulum (cf Fig 5 p 9) The method so proved so suitable that the Thomas caliper treatment of unilateral ases was abandoned From 1957 all patients referred to the h spi a with LCPD have been treated in a wheelchair During the period up to 1964 which is comprised by the present analysis the Physical Therapy Hospital at Hald was an administrative unit under the Orthopaedic Hospital in Arhus with orthopaedic consultants from t ere Thus patien s transferred from other units to Hald are also i luded in the presen material O the 141 patients 27 had been n patients at Hald This includes 11 bilateral cases Five of the 16 unilateral cases had been admitted only temporarily for a short time to relieve t e family of the t erapeutic responsibility and

Table 7 Results of radiological measurements of the right hip in 123 normal children concerning anteversion (ANTEV 1 and ANTEV 2) inclination (CD 1 and CD 2) and neutral rotation of the femoral condyle (O) Inward rotation ($O<0$) Outward rotation ($O>0$) Angles (degrees) age (years) F = female

No	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	O
1	3 5	24	25	137	135	6
2 F	3,5	36	40	143	141	4
3	3 5	42	41	140	140	–3
4	3 5	21	28	127	125	4
5	3 5	22	28	139	138	11
6	3 5	22	27	130	128	5
7	3 5	23	25	132	129	7
8	3 5	39	37	142	142	3
9	4 0	30	40	134	128	3
10 F	4 0	40	38	137	138	2
11	4 5	27	32	140	137	4
12 F	5 0	32	35	134	136	–8
13	5 0	16	16	147	147	7
14	5 0	24	30	142	138	7
15 F	5 0	32	35	135	134	6
16 F	5 0	23	25	130	129	4
17	5 0	40	44	136	131	5
18	5 5	32	36	135	133	3
19	5 5	29	32	147	144	9
20	6 0	25	22	135	134	–1
21 F	6 0	26	31	137	136	0
22 F	6 0	32	34	139	138	2
23 F	6 0	37	36	144	144	3
24 F	6 0	30	27	152	151	4
25	6 0	26	27	137	136	4
26	6 0	34	42	133	126	2
27	6 0	19	32	148	145	3
28	6 0	23	29	133	132	2
29	6 5	30	28	132	132	0
30	6,5	18	20	136	135	8
31	6 5	29	27	145	144	4

No	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
32	6 5	23	28	137	135	1
33	6,5	25	30	139	138	0
34	7 0	35	40	134	131	–2
35	7 0	32	35	129	127	–3
36	7 0	39	36	140	139	–2
37	7 5	10	9	136	137	5
38 F	7 5	26	35	129	126	3
39	7 5	20	22	137	135	0
40	8 0	26	32	135	134	4
41 F	8 0	32	40	142	140	0
42 F	8 0	25	31	131	129	2
43	8 0	19	23	140	139	–2
44 F	8 0	52	54	136	135	–4
45 F	8 0	27	32	120	118	–6
46	8 0	23	26	130	129	0
47	8 0	20	24	134	133	4
48	8,5	28	28	133	133	0
49	8 5	25	22	141	141	5
50	9 0	36	45	131	129	–10
51	9 0	20	22	134	133	4
52 F	9 0	28	49	118	114	–4
53	9 0	27	34	138	136	0
54 F	9 0	28	32	135	134	–2
55 F	9 0	31	39	121	120	–7
56	9,5	21	20	134	133	4
57	10 0	16	26	139	136	2
58	10 0	10	15	126	128	2
59 F	10 0	18	26	130	128	–3
60 F	10 0	50	55	134	129	–5
61	10 0	14	18	128	128	4
62	10 0	23	30	124	124	1
63 F	10 0	32	39	127	125	–5
64 F	10 0	20	28	127	126	–3
65 F	10 0	29	36	130	129	–6
66	10 5	28	36	132	130	–3
67 F	10 5	41	46	134	132	–3

Table 7 Results of radiological measurements of the right hip in 123 normal children concerning anteversion (ANTEV 1 and ANTEV 2) inclination (CD 1 and CD 2) and neutral rotation of the femoral condyle (Θ) Inward rotation (O<0) Outward rotation (O>0) Angles (degrees) age (years) F = female

No	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	O
1	3 5	24	25	137	135	6
2 F	3 5	36	40	143	141	4
3	3 5	42	41	140	140	–3
4	3 5	21	28	127	125	4
5	3 5	22	28	139	138	11
6	3 5	22	27	130	128	5
7	3 5	23	25	132	129	7
8	3 5	39	37	142	142	3
9	4,0	30	40	134	128	3
10 F	4 0	40	38	137	138	2
11	4 5	27	32	140	137	4
12 F	5 0	32	35	134	136	–8
13	5 0	16	16	147	147	7
14	5 0	24	30	142	138	7
15 F	5 0	32	35	135	134	6
16 F	5 0	23	25	130	129	4
17	5 0	40	44	136	131	5
18	5 5	32	36	135	133	3
19	5 5	29	32	147	144	9
20	6 0	25	22	135	134	–1
21 F	6 0	26	31	137	136	0
22 F	6 0	32	34	139	138	2
23 F	6 0	37	36	144	144	3
24 F	6 0	30	27	152	151	4
25	6 0	26	27	137	136	4
26	6 0	34	42	133	126	2
27	6 0	19	32	148	145	3
28	6 0	23	29	133	132	2
29	6,5	30	28	132	132	0
30	6 5	18	20	136	135	8
31	6 5	29	27	145	144	4

No	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
105 F	14 5	18	24	137	137	–7
106 F	14,5	16	26	140	137	–3
107 F	14,5	43	45	129	130	–6
108	14,5	31	35	138	136	–5
109	15 0	6	8	126	127	0
110	15 0	11	16	118	118	–3
111 F	15 0	30	41	134	131	–7
112	15 0	30	38	135	132	–9
113	15 0	17	25	131	130	–7
114 F	15 0	30	33	131	132	–2
115 F	15,5	42	45	125	126	–10
116 F	15,5	23	36	130	129	–7
117	15 5	29	35	135	134	–9
118 F	16 0	28	31	138	137	–8
119	16 0	20	21	128	129	–5
120 F	16 0	32	37	130	127	–7
121 F	16 0	14	20	131	129	–2
122 F	16 0	16	23	133	133	–2
123	16 0	32	43	133	131	–5

No	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	θ
68	10 5	16	22	135	133	
69 F	11 0	35	40	138	138	6
70 F	11 0	22	38	128	126	–8
71	11,0	24	26	131	131	1
72 F	11 0	21	27	131	129	–1
73 F	11 0	16	22	131	128	–3
74 F	11,0	14	18	132	131	–1
75 F	11,0	34	44	129	127	–8
76 F	11 5	21	25	138	138	–8
77 F	11,5	32	40	133	131	–3
78	11,5	37	48	134	132	–5
79	11,5	31	35	128	126	3
80 F	12,0	7	12	127	127	–6
81	12,0	31	38	135	135	1
82	12 0	31	32	132	132	–7
83 F	12 0	12	19	129	129	–2
84	12 0	27	37	132	131	0
85	12 5	14	18	125	125	–3
86	12 5	18	21	135	134	–4
87 F	12,5	19	25	128	128	–1
88 F	12 5	27	29	126	126	–5
89 F	13 0	8	13	128	127	–8
90 F	13 0	28	36	130	129	–4
91	13,0	21	22	130	130	–6
92	13 0	31	36	153	154	0
93	13 0	14	18	130	131	–1
94	13 0	22	29	136	135	–1
95	13 5	31	32	138	140	0
96 F	14 0	27	34	144	143	–5
97 F	14 0	18	18	139	139	–3
98	14 0	11	14	127	127	–6
99 F	14 0	18	25	150	149	–7
100 F	14 0	29	34	127	127	–3
101	14 0	36	45	135	134	–5
102	14 0	31	31	134	134	–8
103	14 0	21	33	132	131	–6
104 F	14 5	27	39	143	141	–5
						–4

No	Age	ANTEV 1	ANTEV 2	CD 1	CD 2	Θ
105 F	14,5	18	24	137	137	–7
106 F	14,5	16	26	140	137	–3
107 F	14,5	43	45	129	130	–6
108	14 5	31	35	138	136	–5
109	15 0	6	8	126	127	0
110	15 0	11	16	118	118	–3
111 F	15 0	30	41	134	131	–7
112	15 0	30	38	135	132	–9
113	15 0	17	25	131	130	–7
114 F	15 0	30	33	131	132	–2
115 F	15 5	42	45	125	126	–10
116 F	15 5	23	36	130	129	–7
117	15,5	29	35	135	134	–9
118 F	16 0	28	31	138	137	–8
119	16 0	20	21	128	129	–5
120 F	16 0	32	37	130	127	–7
121 F	16 0	14	20	131	129	–2
122 F	16 0	16	23	133	133	–2
123	16 0	32	43	133	131	–5

A FOLLOW UP STUDY OF CHILDREN WITH CONGENITAL DISLOCATION OF THE HIP TREATED WITH VON ROSEN SPLINT IN THE NEONATAL PERIOD

In collaboration with Goran Hansson and Bertil Romanus

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Introduction

It is possible to diagnose congenital dislocation of the hip (CDH) in the neonatal period and the chance of successful therapy increases if the treatment is started immediately (von Rosen 1956 Palmen 1961 Barlow 1962 Fredensborg 1975)

Increased anteversion of the femoral neck has been reported by several authors to be part of the anatomical derangement in CDH (Badgley 1943, Edgren & Laurent 1956 Shands & Steele 1958 Fabry et al 1973)

Increased anteversion of the femoral neck has also been proposed to be a factor predisposing to osteoarthrosis of the hip joint (Alvik 1960 Morscher 1967, Muller 1971)

Alvik (1960) recommended operation with derotation osteotomy at the proximal end of the fe mur in children with increased anteversion of the femoral neck as a single sign of dysplasia

Fredensborg (1975) reported on 111 children with CDH treated with von Rosen splint for 3 months He evaluated the results obtained by measuring the centre-edge angle (CE angle – Wi berg 1939) and the spherical index (Fredensborg 1975) and classified all except 2 children as normal

Cyvin (1977) on the other hand reported on increased angles of anteversion of the femoral neck when re examining 129 children with CDH who had been treated with the Frejka pillow in the neonatal period (Frejka 1941)

The purpose of this follow up investigation was to study the anteversion and inclination of the femoral neck in children at the age of 6 – 9 years treated with the von Rosen splint during the neonatal period because of unstable hips (CDH)

The angles of anteversion (ANTEV 1 and ANTEV 2) (fig 19) and inclination of the femoral neck (CD 1) have been measured by the technique defined in chapter I and II The standard error of this method has been determined to be 3° when measuring angles of anteversion and 2° when measuring inclination With a standard error of 3° when measuring anteversion the SD of differ ence in anteversion between normal symmetrical hips is $SD = \sqrt{3^2 + 3^2} \approx 4\ 25^\circ$ and $2\ SD \approx 8\ 5^\circ$ Additionally the centre-edge angle (CE angle – Wiberg 1939) was measured as well as the spherical index introduced by Fredensborg (1975)

The roentgenograms were also evaluated by an independent radiologist

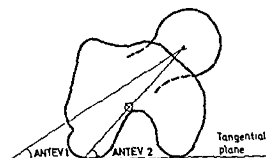


Fig 19 Axial view of the right femur seen in the direction of the long ideal axis with the 2 anteversion angles ANTEV 1 and ANTEV 2

Material

Between 1968 and 1970 there were 19 259 live births in the two departments of obstetrics in Gothenburg. 482 children (326 girls and 156 boys) with suspected unstable hips were referred to the Department of Orthopaedic Surgery within the first 10 days of life 125 children demonstrated on clinical examination by the orthopaedic surgeons unstable hips (Ortolani 1937 Palmén 1961 Barlow 1962) Twenty-eight of these 125 children were selected (22 girls and 6 boys) for this study Only children where the clinical diagnosis of hip instability was well documented were included (Hansson & Romanus 1975) No distinction was made between dislocatable and dislocated hip joints

Primary clinical assessment

Eleven girls with unstable hips had unilateral and 11 had bilateral hip instability when first examined (table 8) Four of the 6 boys with unstable hips had unilateral and 2 had bilateral hip instability when first examined (table 8)

Table 8 Unstable hips at primary clinical assessment

	Left hip	Right hip	Bilateral	Total
Girls	5	6	11	22
Boys	2	2	2	6
Total	7	8	13	28

Choice and length of abduction treatment

All children had abduction treatment with the von Rosen splint 4 cases less than 6 weeks, 15 cases between 6 – 9 weeks and 9 cases more than 9 weeks (table 12) Primary abduction treatment with the von Rosen splint was followed by a period of abduction treatment with Frejka pillow in all cases except 3 Total abduction time varied between 9 – 29 weeks (table 12)

Statistics

Standard statistical methods were used Fischer s test for pair wise comparisons and Student s t test The statistical significance (p) was tested at the 0 05 level

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The roentgenograms were also evaluated by an independent radiologist

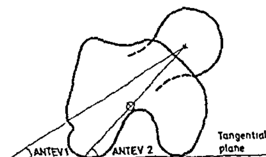


Fig 19 Axial view of the right femur seen in the direction of the long ideal axis with the 2 antever sion angles ANTEV 1 and ANTEV 2.

Material

Between 1968 and 1970 there were 19 259 live births in the two departments of obstetrics in Gothenburg 482 children (326 girls and 156 boys) with suspected unstable hips were referred to the Department of Orthopaedic Surgery within the first 10 days of life 125 children demon strated on clinical examination by the orthopaedic surgeons unstable hips (Ortolani 1937 Pal mén 1961 Barlow 1962) Twenty-eight of these 125 children were selected (22 girls and 6 boys) for this study Only children where the clinical diagnosis of hip instability was well documented were included (Hansson & Romanus 1975) No distinction was made between dislocatable and dislocated hip joints

Primary clinical assessment

Eleven girls w th unstable hips had unilateral and 11 had bilateral hip instability when first ex amined (table 8) Four of the 6 boys with unstable hips had unilateral and 2 had bilateral hip in stability when first examined (table 8)

Table 8 Unstable hips at primary clinical assessment

	Left hip	Right hip	Bilateral	Total
Girls	5	6	11	22
Boys	2	2	2	6
Total	7	8	13	28

Choice and length of abduction treatment

All children had abduction treatment with the von Rosen *splint* *4 cases less than* 6 weeks, 15 cases between 6 – 9 weeks and 9 cases more than 9 weeks (*table 12*) Primary abduction treat ment with the von Rosen *splint* was followed by a period of *abduction treatment* with Frejka pillow in all cases except 3 Total abduction time varied between 9 – 29 weeks (table 12)

Statistics

Standard statistical methods were used Fischer s test for pair wise comparisons and Student s t test The statistical significance (p) was tested at the 0 05 level

A FOLLOW UP STUDY OF CHILDREN WITH CONGENITAL DISLOCATION OF THE HIP TREATED WITH VON ROSEN SPLINT IN THE NEONATAL PERIOD

In collaboration with Goran Hansson and Bertil Romanus

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Introduction

It is possible to diagnose *congenital dislocation of the hip (CDH) in* the neonatal period and the chance of successful therapy increases if the treatment is started immediately (von Rosen 1956 *Palmén 1961 Barlow 1962 Fredensborg 1975)*

Increased anteversion of the femoral neck has been reported by several authors to be part of the anatomical derangement in CDH (Badgley 1943, Edgren & Laurent 1956 Shands & Steele 1958 Fabry et al 1973)

Increased anteversion of the femoral neck has also been proposed to be a factor predisposing to osteoarthrosis of the hip joint *(Alvik 1960* Morscher 1967 Muller 1971)

Alvik (1960) recommended operation with derotation osteotomy at the proximal end of the femur in children with increased anteversion of the femoral neck as a single sign of dysplasia

Fredensborg (1975) reported on 111 children with CDH treated with von Rosen splint for 3 months He evaluated the results obtained by measuring the centre-edge angle (CE angle – Wiberg 1939) and the spherical index (Fredensborg 1975) and classified all except 2 children as normal

Cyvin (1977) on the other hand reported on increased angles of anteversion of the femoral neck when re examining 129 children with CDH who had been treated with the Frejka pillow in the neonatal period (Frejka 1941)

The purpose of this follow up investigation was to study the anteversion and inclination of the femoral neck in children at the age of 6 – 9 years treated with the von Rosen splint during the neonatal period because of unstable hips (CDH)

The angles of anteversion (ANTEV 1 and ANTEV 2) (fig 19) *and inclination of the femoral neck* (CD 1) have been measured by the technique defined in chapter I and II The standard error of this method has been *determined to be* 3° *when measuring* angles of anteversion and 2° when measuring inclination With a standard error of 3° when measuring anteversion the SD of difference *in anteversion* between normal symmetrical hips is $SD = \sqrt{3^2 + 3^2} \approx 4.25°$ and $2\,SD \approx 8.5°$ Additionally the centre edge angle (CE angle – Wiberg 1939) was measured as well as the *spherical index introduced* by Fredensborg (1975)

The roentgenograms were also evaluated by an independent radiologist

Comparison of unstable hips and hips in normal children

1 Anteversion measured as ANTEV 1 and ANTEV 2 was within the limit of ± 2 SD for the reference material consisting of 123 hips (chapter III) except in 1 unstable hip measured as ANTEV 1 and in 3 hips measured as ANTEV 2 (figures 20 – 21) The inclination was within the ± 2 SD in 39 of 41 unstable hips (fig 22)

Fig 20 (left) and Fig. 21 (right) The anteversion values (ANTEV 1 and ANTEV 2) in right and left hips in 28 children with unstable hips at birth. Girls and boys are represented in different diagrams The anteversion was measured at the age of 6 – 9 years and compared with the anteversion of 123 normal children in the reference material (70 boys and 53 girls) represented by the regression mean and ± 2 SD limits.

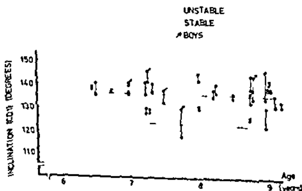


Fig 22 The inclination values (CD I) in right and left hips in 28 children with unstable hips at birth. Girls and boys are represented together The regression mean and ± 2 SD limits for the reference material of 123 normal children are included for comparison.

Results

The results obtained are presented in table 12 (page 40)

Conventional radiographic evaluation In 7 children (8 hips) the findings were considered as pathological (shallow acetabulum, short femoral neck and/or horizontal epiphyseal plate) and 5 children (9 hips) were judged as having a valgus deformity (table 12)

CE angles were all ⩾ 15° except for one child (13°) and the spherical index was > 0 36 in all children (table 12)

Measurements of anteversion (ANTEV 1 and ANTEV 2) and inclination (CD 1)

a. Children with unilateral hip instability ($n = 15$)

No difference between unstable and stable hips was found regarding angles of ANTEV 1, ANTEV 2 and CD 1 (table 9)

Table 9 Mean value and SD of anteversion and inclination (degrees) in children with unilateral hip instability ($n = 15$)

Angle	Unstable hip	Stable hip	Difference unstable – stable hip	p
ANTEV 1	31 ± 6 8	28 ± 5 3	2 9 ± 7 8	>0 05
ANTEV 2	38 ± 8 4	33 ± 11 9	4 4 ± 10 6	>0 05
CD 1	135 ± 5 0	135 ± 5 9	0.3 ± 5 7	>0 05

b Children with bilateral hip instability ($n = 13$)

No difference between right and left hip was found in children with bilateral hip instability regarding the angle of ANTEV 1, ANTEV 2 and CD 1 (table 10)

Table 10 Mean value and SD of anteversion and inclination (degrees) in children with bilateral hip instability ($n = 13$)

Angle	$\frac{dx + sin}{2}$	dx – sin	p
ANTEV 1	31 ± 8 0	3 0 ± 8 0	>0 05
ANTEV 2	37 ± 9 1	2 9 ± 8 2	>0 05
CD 1	135 ± 6 4	–1 ± 3 8	>0 05

When comparing children with unilateral and bilateral hip instability regarding the angles ANTEV 1 ANTEV 2 and CD 1 *no significant difference was found*

There was no correlation between anteversion of the femoral neck (ANTEV 1) and length of abduction treatment

version is greater than the functional anteversion This means that the children with reported increased anteversion in Cyvin s study might have a still higher anteversion if measured relative to the femoral condyles

The results of our investigation support the idea that it is necessary to choose a more rigid form of immobilization of the hip joints to obtain normal angles of anteversion When comparing our experiences with those of Cyvin it must be pointed out that he included children with neurological disorders and there have been earlier reports on increased anteversion without dislocation of the hip joints in children with cerebral paresis (Beals 1969 Fabry et al 1973)

There is no evidence of asymmetrical anteversion in healthy children [Norman 1978 Asplund & Henriksson (chapter III)] Cyvin (1977) reported on asymmetrical development of anteversion of the femoral neck in 28 % of the children with unstable hips Seven out of 28 children in this study (4 with bilateral hip instability and 3 with unilateral hip instability) had a difference in the angles of anteversion (ANTEV 1 and ANTEV 2) between right and left hip of 9 or more indicating asymmetrical development In 2 out of 3 children with unilateral hip instability the anteversion was higher on the unstable side

When interpreting the AP films of the pelvis there was an impression of valgity in 5 children (9 hips) The inclination calculated was however within normal limits (135 – 146)

This study has shown that in children with CDH the anteversion and inclination are within normal limits However the conventional radiological evaluation demonstrated abnormalities such as horizontal tilting of the epiphyseal plate (fig 23) and shortening of the femoral neck These changes will be the subject for further studies

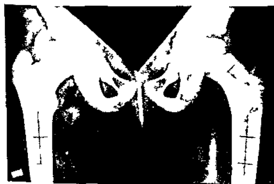


Fig. 23 X ray of the right and left hip in a child (patient no 20 female 7 years) treated with von Rosen splint in the neonatal period because of unstable right hip At the examination a marked epiphyseal tilting was found on the right side with a short femoral neck. Left hip normal.

Conclusions

In studying 28 children (22 girls and 6 boys) with unstable hips treated with the von Rosen splint during the neonatal period the following results were obtained

1 In children with CDH there were no differences between stable and unstable hips with regard to anteversion and inclination

2 The measured angles of unstable hips did not differ from those of healthy children of the same age

3 The length of abduction treatment did not influence the angle of anteversion of the femoral neck

4 Minor disturbances in development of the hip joints were seen

2 12 girls and 27 boys in the reference material (chapter III) were of the same age as the children with unstable hips (5 5 – 9 5 years) (table 7)

When comparing the anteversion and the inclination (ANTEV 1, ANTEV 2) in 22 girls with un stable hips with 12 girls with normal hips of the same age, no statistical difference was found The same result was found when comparing inclination (CD 1) Nor was there a difference be- tween 6 boys with unstable hips and 27 boys with normal hips of the same age (table 11)

Table 11 Angles of anteversion and inclination (degrees) in 28 children with unstable hips and 39 children with normal hips

Angle	Girls		Boys	
	Unstable n = 22	Normal n = 12	Unstable n = 6	Normal n = 27
ANTEV 1	31 ± 6 3	31 ± 7 4	31 ± 10 7	26 ± 7 0
ANTEV 2	38 ± 7 4	37 ± 7 8	38 ± 13 0	29 ± 8 1
CD 1	135 ± 5 0	134 ± 10 4	136 ± 9 9	136 ± 4 7

Discussion

There have been several reports of failures when treating children with unstable hips during the neonatal period with different kinds of splints (Hiertonn & James 1968, Fellander et al 1970 Walker 1971 Williamson 1972 Bjerkreim 1974 Cyvin 1977) Several reports have also been presented on iatrogenic effects of abduction treatment in children with CDH (Little et al 1960 Dooley 1964 Salter et al 1969, Gage & Winter 1972 Gore 1974) The opinions therefore vary about the type of abduction treatment that should be used Salter et al (1969) postulated that the adverse effects seen by abduction treatment depend on trauma to the blood vessels of the femoral head He stressed the importance of not forcing the femoral head into the acetabulum and recommended the use of Frejka pillow postulating The hips are not rigidly immobilized yet maintained in a stable position This type of splint is particularly useful for the newborn in fants According to Hiertonn & James (1968) it is necessary to choose a more rigid fixation of the hip joints and they recommend the use of the von Rosen splint

This investigation has shown normal anteversion and inclination in children with unstable hips treated with the von Rosen splint during the neonatal period and these results are to be com pared with the reports on increased anteversion in children treated with the Frejka pillow during the neonatal period (Bjerkreim 1974 Cyvin 1977) Eriksson & James (1970) also found a ten dency to increased angles of anteversion in children treated with unspecified splint for unstable hips during the neonatal period However the number of patients in their study was too small for statistical evaluation The anteversion measured by Cyvin Eriksson & James was the angle between the femoral neck and the frontal plane i e a functional anteversion This functional anteversion was also studied by Asplund & Henriksson (chapter III) who demonstrated that when the anteversion is above average there is usually an inward rotation of the tangential plane to the dorsal part of the femoral condyles i e when the anteversion is high the anatomical ante

version is greater than the functional anteversion This means that the children with reported increased anteversion in Cyvin s study might have a still higher anteversion if measured relative to the femoral condyles

The results of our investigation support the idea that it is necessary to choose a more rigid form of immobilization of the hip joints to obtain normal angles of anteversion When comparing our experiences with those of Cyvin it must be pointed out that he included children with neurological disorders and there have been earlier reports on increased anteversion without dislocation of the hip joints in children with cerebral paresis (Beals 1969 Fabry et al 1973)

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This study has shown that in children with CDH the anteversion and inclination are within normal limits However the conventional radiological evaluation demonstrated abnormalities such as horizontal tilting of the epiphyseal plate (fig 23) and shortening of the femoral neck These changes will be the subject for further studies



Fig. 23 X-ray of the right and left hip in a child (patient no 20 female 7 years) treated with von Rosen splint in the neonatal period because of unstable right hip At the examination a marked epiphyseal tilting was found on the right side with a short femoral neck. Left hip normal.

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Table 12 Results of radiological measurements in a follow up study of CDH (22 girls and 6 boys) F = female M = male U = unstable side Visual impressions from roentgenograms of the hips N = normal. V = valgity P = disturbed anatomy The anteversion was measured according to 2 definitions (ANTEV 1 and ANTEV 2) Inclination (CD 1) Angles in degrees

No	Sex	Clinical assessm		Treatment v R	F	Age at re-examin	X ray visual impression		CE angle		Spherical index		ANTEV 1		ANTEV 2		CD 1	
		DX	SIN	weeks		years	DX	SIN	DX	SIN	DX	SIN	DX	SIN	DX	SIN	DX	SIN
1	F	U	–	7	4	9	N	N	25	28	0 40	0 45	25	20	33	23	130	133
2	F	U	–	12	–	9	V	N	25	27	0 43	0 43	37	30	47	36	135	130
3	F	U	U	6	6	9	V	V	23	23	0 45	0 43	40	43	53	55	140	141
4	F	U	–	10	10	9	N	N	24	26	0 40	0 43	38	41	44	47	137	137
5	F	U	–	12	–	9	N	N	27	25	0 44	0 44	29	31	40	42	138	138
6	F	U	–	6	6	8	N	N	33	34	0 40	0 37	30	50	42	63	134	145
7	F	U	U	9	4	8	N	N	23	23	0 44	0 46	28	31	36	36	122	129
8	F	U	U	9	8	8	V	V	35	35	0 44	0 44	26	21	34	35	138	143
9	F	U	U	8	18	8	N	N	28	35	0 46	0 47	36	25	34	30	126	125
10	M	–	U	6	6	8	P	P	19	17	0 44	0 39	4	14	10	17	133	143
11	M	U	U	6	6	8	N	N	30	28	0 40	0 39	39	49	42	60	132	136
12	F	–	U	13	–	8	N	P	20	13	0 45	0 42	26	26	32	33	134	136
13	F	–	U	12	–	8	N	N	30	32	0 40	0 44	21	35	29	47	136	139
14	F	–	U	12	7	8	N	N	27	39	0 38	0 41	26	29	36	32	134	137
15	F	U	U	6	7	8	N	N	26	24	0 38	0 41	33	29	40	36	129	129
16	F	U	U	12	17	8	N	N	27	28	0 42	0 42	42	42	49	49	143	141
17	M	U	–	6	7	7	P	N	20	23	0 42	0 41	39	35	45	34	117	129
18	M	U	–	12	4	7	N	P	27	18	0 40	0 37	25	20	29	23	137	132
19	F	U	U	6	7	7	N	N	25	25	0 41	0 42	29	20	34	24	129	127
20	F	U	–	3	7	7	P	N	19	24	0 40	0 39	34	26	33	26	128	127
21	F	U	U	3	11	7	P	N	17	21	0 38	0 40	31	31	44	31	140	136
22	M	U	U	12	8	7	V	V	26	22	0 37	0 38	29	30	38	34	146	141
23	F	U	U	6	3	7	N	N	36	36	0 40	0 40	37	16	34	24	135	141
24	M	–	U	7	5	7	V	V	29	33	0 42	0 40	25	34	24	49	138	140
25	F	–	U	6	6	7	N	N	19	19	0 44	0 43	36	37	36	40	136	135
26	F	U	U	1	10	6	N	N	26	29	0 44	0 43	14	17	23	22	137	137
27	F	U	U	6	7	6	P	N	19	25	0 41	0 41	37	28	44	31	136	140
28	F	–	U	2	11	6	N	N	38	40	0 42	0 43	33	36	40	37	137	137

A FOLLOW UP STUDY OF CHILDREN WITH FEMORAL FRACTURES

In collaboration with Harald Asplund and Bjorn Henrikson
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University of Göteborg Goteborg Sweden

Introduction

Femoral shaft fractures in children have a natural tendency to heal and conservative treatment with traction is therefore the usual mode of therapy Some spontaneous correction of angular deformity occurs during the healing process (Vontobel et al 1961 Weber 1969) but not of mal rotation It has been claimed that these malrotations may play an important part in the develop ment of arthrosis of the hip and knee (Muller 1967) It has also been pointed out that clinical symptoms occur when the torsion exceeds 20° (Nicod 1967) Torsion alters the anteversion in the hip and Muller considers that anteversion of more than 30 and retroversion of the neck of the femur by more than 5° causes arthrosis of the hip In order to avoid this corrective osteo tomy has been recommended (Vontobel et al 1961 van Joost & Gastkemper 1972 Zenker 1972) For determination of the degree of torsion in the fracture both clinical (Kootstra 1973 van Joost & Gastkemper 1972) and radiological methods have been used The radiological methods are based on measurement of the difference in anteversion between the healthy and the fractured side usually by means of the methods proposed by Dunlap et al (1953) and Rippstein (1955) Measurements performed in this way assume that both the knee joints and the femur are symmetrically positioned when the lower legs are symmetrically positioned conditions which are difficult to achieve during clinical measurement The error of measurement in clinical prac tice is therefore difficult to evaluate The above mentioned authors as well as Hamacher (1974) have estimated the error of measurement in clinical practice to be 5° – 10 As pointed out by Norman (1969) knowledge of the orientation of the knee joint is necessary for reliable measure ments of the angle of anteversion With a measuring error of 5° with the Rippstein method a dif ference of 5° between the fractured and non fractured side as proposed by Benum et al (1979) does not necessarily indicate a torsion of the same degree

With the Rippstein method differences of 10° – 15° between right and left side can appear when measuring the anteversion of normal hips Ruby et al (1979) reported such differences when using the Ryder-Crane method which is a similar biplanar method

The aim of this study is to assess the torsion in healed femoral shaft fractures using a method in which the methodological error is known (chapter I and II) The dislocation of the fractures es pecially the torsion has been compared with the childrens clinical symptoms and signs

Determination of the torsion presupposes a knowledge of the original anatomy Since this is dif ficult to obtain from ordinary roentgenograms it is natural to compare with the contralateral side In normal children there is no evidence of asymmetry between right and left hip (Norman 1978 and chapter III) Thus we define the torsion as the difference in anteversion between the non fractured and the fractured sides (fig 24) Since the femoral shaft has been fractured the

Table 12 Results of radiological measurements in a follow up study of CDH (22 girls and 6 boys) F = female M = male U = unstable side Visual impressions from roentgenograms of the hips N = normal. V = valgity P = disturbed anatomy The anteversion was measured according to 2 definitions (ANTEV 1 and ANTEV 2) Inclination (CD 1) Angles in degrees

No	Sex	Clinical assessm		Treatment v R	F	Age at re examin.	X ray visual impression		CE angle		Spherical index		ANTEV 1		ANTEV 2		CD 1	
		DX	SIN	weeks		years	DX	SIN	DX	SIN	DX	SIN	DX	SIN	DX	SIN	DX	SIN
1	F	U	–	7	4	9	N	N	25	28	0 40	0 45	25	20	33	23	130	133
2	F	U	–	12	–	9	V	N	25	27	0 43	0 43	37	30	47	36	135	130
3	F	U	U	6	6	9	V	V	23	23	0 45	0 43	40	43	53	55	140	141
4	F	U	–	10	10	9	N	N	24	26	0 40	0 43	38	41	44	47	137	137
5	F	U	–	12	–	9	N	N	27	25	0 44	0 44	29	31	40	42	138	138
6	F	U	–	6	6	8	N	N	33	34	0 40	0 37	30	50	42	63	134	145
7	F	U	U	9	4	8	N	N	23	23	0 44	0 46	28	31	36	36	122	129
8	F	U	U	9	8	8	V	V	35	35	0 44	0 44	26	21	34	35	138	143
9	F	U	U	8	18	8	N	N	28	35	0 46	0 47	36	25	34	30	126	125
10	M	–	U	6	6	8	P	P	19	17	0 44	0 39	4	14	10	17	133	143
11	M	U	U	6	6	8	N	N	30	28	0 40	0 39	39	49	42	60	132	136
12	F	–	U	13	–	8	N	P	20	13	0 45	0 42	26	26	32	33	134	136
13	F	–	U	12	–	8	N	N	30	32	0 40	0 44	21	35	29	47	136	139
14	F	–	U	12	7	8	N	N	27	39	0 38	0 41	26	29	36	32	134	137
15	F	U	U	6	7	8	N	N	26	24	0 38	0 41	33	29	40	36	129	129
16	F	U	U	12	17	8	N	N	27	28	0 42	0 42	42	42	49	49	143	141
17	M	U	–	6	7	7	P	N	20	23	0 42	0 41	39	35	45	34	117	129
18	M	U	–	12	4	7	N	P	27	18	0 40	0 37	25	20	29	23	137	132
19	F	U	U	6	7	7	N	N	25	25	0 41	0 42	29	20	34	24	129	127
20	F	U	–	3	7	7	P	N	19	24	0 40	0 39	34	26	33	26	128	127
21	F	U	U	3	11	7	P	N	17	21	0 38	0 40	31	31	44	31	140	136
22	M	U	U	12	8	7	V	V	26	22	0 37	0 38	29	30	38	34	146	141
23	F	U	U	6	3	7	N	N	36	36	0 40	0 40	37	16	34	24	135	141
24	M	–	U	7	5	7	V	V	29	33	0 42	0 40	25	34	24	49	138	140
25	F	–	U	6	6	7	N	N	19	19	0 44	0 43	36	37	36	40	136	135
26	F	U	U	1	10	6	N	N	26	29	0 44	0 43	14	17	23	22	137	137
27	F	U	U	6	7	6	P	N	19	25	0 41	0 41	37	28	44	31	136	140
28	F	–	U	2	11	6	N	N	38	40	0 42	0 43	33	36	40	37	137	137

None of the 4 fractures with increased anteversion on the fracture side i e indicating inward torsion exhibited a greater difference than 5 in anteversion

The 4 fractures fixed by osteosynthesis all had smaller torsion than 5° Since the surgical procedure allowed restitution of symmetrical anatomy and thus essentially the same anteversion bilaterally the measurements in these 4 cases may be regarded as a control of the accuracy of measurement i e original symmetry between right and left

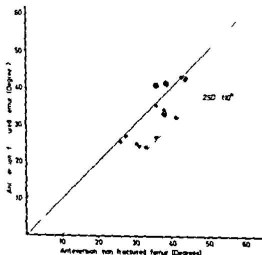


Fig 25 The degree of torsion in 28 femoral fractures. Each point represents the anteversion in one patient for the femur on the fractured and non fractured side. ⊙ denotes AO synthesis of four femoral fractures The limit for variation in the error of measurement is indicated in the diagram with 2 SD = ± 10°

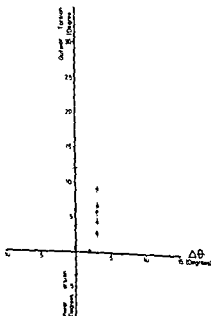


Fig 26 The relationship between the fracture torsion and the difference in inclination from horizontal of the condylar planes on the fractured and non fractured sides Δθ is illustrated. Δθ is usually positive owing to reduced anteversion on the fractured side. Δθ is ≤ 0 if the fracture has caused increased anteversion on the fractured side. When Δθ ≤ 3° the torsion was < 12

long ideal shaft axis from the knee to the proximal femur (Billing 1954) has not been used The anteversion was therefore determined relative to the proximal short straight axis of the femur

The anteversion was measured according to Norman (1969) and is defined as the direction angle of the capital centre relative to the tangential plane of the femoral condyles, as seen in the direction of the short axis (fig 24)

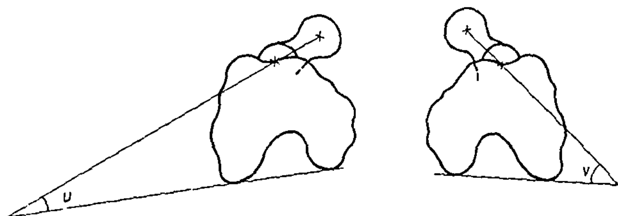


Fig 24 The fractured (right) and non fractured (left) femur in the axial projection. The line through the centre of femoral head and axis of the shaft of the femur forms an anteversion angle u and v respectively with the condylar plane Torsion v – u

The radiological examination was performed as described in chapter II, with the patient placed supine with the pelvis horizontal and the lower leg hanging freely on the side to be investigated The tangential plane of the dorsal parts of the condyles of the knee was determined on both sides by fluoroscopy and read off on the scale of the x ray apparatus The measurement errors in model experiments for this method of determining the angle of anteversion relative to the short proximal axis are 3 5° and are thus negligibly greater than when the ideal axis is used (Blomberg & Henriksson chapter I) The SD for difference between symmetrical right and left hip is $\sqrt{3\ 5^2 + 3\ 5^2} \approx 5°$ 2 SD $\approx 10°$

Material

The follow up investigation comprises 28 children with consecutive unilateral femoral shaft fractures (14 boys and 14 girls) Their ages ranged between 5 and 16 years the mean age being 9 5 years The interval between the occurrence of the fracture and the investigation varied between 2 months and 4 years Of the 28 fractures 24 were treated with traction Twenty of these 24 fractures were situated in the central part of the shaft 2 in the proximal part and 2 in the distal part The remaining 4 fractures were treated by osteosynthesis according to the AO method Three of these fractures were situated in the central part of the shaft and one in the distal part

Results

Radiological measurement of the angle of anteversion

In 21 of the 24 fractures treated with traction the anteversion was reduced on the fractured side (fig 25) i e indicating outward torsion of the distal fragment of the femur However in only 6 cases the outward torsion of the distal fragment was greater than 2 SD for the methodological error

None of the 4 fractures with increased anteversion on the fracture side i e indicating inward torsion exhibited a greater difference than 5° in anteversion

The 4 fractures fixed by osteosynthesis all had smaller torsion than 5° Since the surgical procedure allowed restitution of symmetrical anatomy and thus essentially the same anteversion bilaterally the measurements in these 4 cases may be regarded as a control of the accuracy of measurement i e original symmetry between right and left

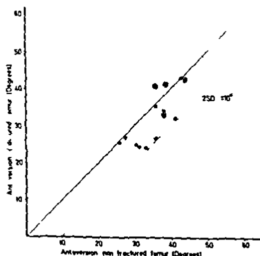


Fig 25 The degree of torsion in 28 femoral fractures. Each point represents the anteversion in one patient for the femur on the fractured and non fractured side. ⊙ denotes AO synthesis of four femoral fractures The limit for variation in the error of measurement is indicated in the diagram with 2 SD = ± 10

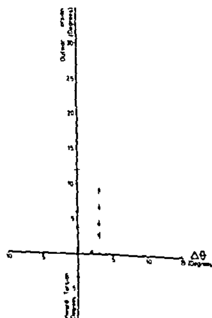


Fig 26 The relationship between the fracture torsion and the difference in inclination from horizontal of the condylar planes on the fractured and non fractured sides ΔΘ is illustrated. ΔΘ is usually positive owing to reduced anteversion on the fractured side. ΔΘ is < 0 if the fracture has caused increased anteversion on the fractured side. When ΔΘ < 3° the torsion was < 12°

long ideal shaft axis from the knee to the proximal femur (Billing 1954) has not been used The anteversion was therefore determined relative to the proximal short straight axis of the femur

The anteversion was measured according to Norman (1969) and is defined as the direction angle of the capital centre relative to the tangential plane of the femoral condyles as seen in the direction of the short axis (fig 24)

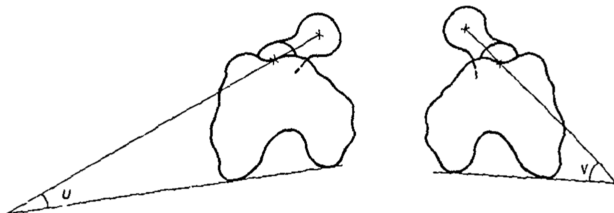


Fig 24 The fractured (right) and non fractured (left) femur in the axial projection The line through the centre of femoral head and axis of the shaft of the femur forms an anteversion angle u and v, respectively with the condylar plane Torsion v – u

The radiological examination was performed as described in chapter II with the patient placed supine with the pelvis horizontal and the lower leg hanging freely on the side to be investigated The tangential plane of the dorsal parts of the condyles of the knee was determined on both sides by fluoroscopy and read off on the scale of the x ray apparatus The measurement errors in model experiments for this method of determining the angle of anteversion relative to the short proximal axis are 3 5° and are thus negligibly greater than when the ideal axis is used (Blomberg & Henriksson chapter I) The SD for difference between symmetrical right and left hip is $\sqrt{3.5^2 + 3.5^2} \approx 5°$ 2 SD $\approx 10°$

Material

The follow up investigation comprises 28 children with consecutive unilateral femoral shaft fractures (14 boys and 14 girls) Their ages ranged between 5 and 16 years the mean age being 9 5 years The interval between the occurrence of the fracture and the investigation varied between 2 months and 4 years Of the 28 fractures 24 were treated with traction Twenty of these 24 fractures were situated in the central part of the shaft 2 in the proximal part and 2 in the distal part The remaining 4 fractures were treated by osteosynthesis according to the AO method Three of these fractures were situated in the central part of the shaft and one in the distal part

Results

Radiological measurement of the angle of anteversion

In 21 of the 24 fractures treated with traction the anteversion was reduced on the fractured side (fig 25) i e indicating outward torsion of the distal fragment of the femur However in only 6 cases the outward torsion of the distal fragment was greater than 2 SD for the methodological error

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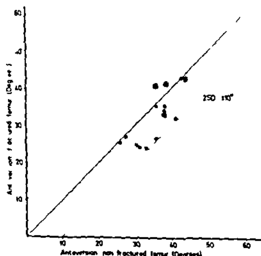


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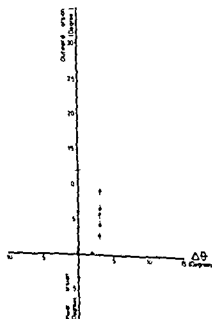


Fig 26 The relationship between the fracture torsion and the difference in inclination from horizontal of the condylar planes on the fractured and non fractured sides $\Delta\Theta$ is illustrated. $\Delta\Theta$ is usually positive owing to reduced anteversion on the fractured side. $\Delta\Theta$ is < 0 if the fracture has caused increased anteversion on the fractured side. When $\Delta\Theta < 3°$ the torsion was $< 12°$

Table 13 Torsion for different positions and types of fracture (degrees) 28 femoral fractures altogether Figures within brackets denote 4 fractures operated upon according to the AO method

Type of fracture \ Torsion	< 5°	5° – 10°	10° – 15°	15° – 20°	> 20°	n
Proximal	2					2
Mid diaphyseal						
Transversal	4 (3)	3		2	1	13
Oblique	4	4	1		1	10
Distal	(1)	1		1		3

Table 13 demonstrates the torsions classified by transverse and oblique fractures The material is too small to allow conclusions about whether different fracture surfaces are associated with differences in the degree of torsion No difference could be detected Four of the 6 fractures with outward malrotation of > 10° had a moderate varus angulation The two remaining fractures were oblique fractures without visible dislocation from the axis In 10 cases of 12 without varus or valgus dislocation the torsion was < 10° Valgus dislocation was uncommon in this material 5 cases In 3 of these 5 cases there was a tendency to slight inward torsion (fig 27)

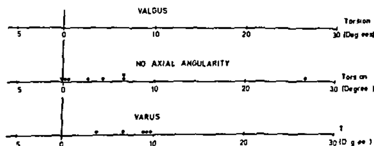


Fig 27 Torsion for different axial dislocation (varus valgus and non axial dislocation) The axial dislocation has been assessed from the frontal projection of the femur when the fracture has healed

Clinical investigation

No evidence of asymmetric gait could be found in any child Clinical classification into small and large torsions was not possible In children found radiologically to have small malrotations (< 10°) no evidence of a difference in the capacity for inward and outward torsion of the hips was found but such a difference was found in some children with large torsions

Four children had subjective symptoms The study has not given any indications that the subjective symptoms can be explained by the torsion in the fracture except in one case — a 16 year old girl with a malrotation of 18° The subjective symptoms four years after the fracture consisted of a feeling of tautness in the front of the thigh clicking in the right ankle during gait and difficulty in running one year after the fracture occurred The patient walks well without limping and can sit on her haunches and run. The other three children with subjective symptoms had torsion of < 10° In two of these three cases the subjective symptoms could be explained by pain in the knees owing to concomitant patellar fractures These two children also had difficulty in sitting on their haunches

Discussion

Like Yano & Sawada (1975) we have found that conservative treatment of femoral fractures with traction in children usually causes outward torsion of the distal fragment The total frequency of outward torsion is higher in our study than has previously been reported (Yano & Sawada 1975 Piroth & Bliesener 1977) Yano & Sawada who used Rippstein s method of measurement reported three cases of inward torsion of > 15° among 31 cases. Even allowing for a standard error of measurement of 5° with Rippstein s method the occurrence of inward torsion must be regarded as proven. In one case they found an inward torsion of 20 – 25° The frequency of large outward torsion (> 15°) in our study (20 %) is essentially consistent with the figure of 25 % found by the above authors with 30° as the upper limit for outward torsion However outward torsion after traction may sometimes be as great as about 40° (Probst 1977)

The torsions after AO synthesis were small as found in previous studies (Kootstra 1973)

No difference in torsion between transverse and oblique fractures was detected The study suggests however that outward torsion is associated with moderate varus dislocation at least in cases of large malrotations This association has not previously been reported Varus and valgus dislocations correct spontaneously less often than ad latus dislocations (Vontobel et al 1961)

Since the femur including the distal fragment is curved in the lateral projection an outward torsion of the distal fragment may give the impression of varus in the frontal projection. This may be one explanation why varus dislocation appears to be associated with large outward torsion.

No clear connection between subjective symptoms and gait disturbances owing to torsion has been found in this study The incidence of subjective symptoms was strikingly low and was not related to torsion In two of the four children with subjective symptoms the symptoms could be explained by concomitant patellar fractures The torsion in these cases was slight Only in one case were the symptoms considered to be due to the torsion. This patient had an outward torsion of 18 and experienced a feeling of tautness in the front of her thigh and moderate pain and clicking in her ankle Symptoms of this type have been reported in connection with torsion (van Joost & Gastkemper 1972 Kootstra 1973)

Retroversion of > 5° is considered to cause coxarthrosis in adulthood (Muller 1967) In our study all outward malrotations were less than the anteversion on the contralateral side This means that symmetry between the right and left knee during forward gait does not cause retroversion on the fracture side The lower limit of torsion as an indication for corrective osteotomy varies. Zenker (1972) gives a limit of 30° and Vontobel et al (1961) propose a figure of 15° for outward torsion For inward malrotation the same authors propose 5 – 10 At present we do not consider that there are clear indications for osteotomy in our material The possibility of subjective symp-

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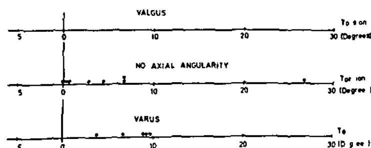


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toms occurring later must be borne in mind however since the duration of follow up in this study is only a few years

Since clinical assessment of torsions appears to be difficult a simple method of estimating the angle of anteversion is desirable if subjective symptoms and gait disturbances occur An association between anteversion and condylar tangent inclination has been demonstrated by Asplund & Henriksson (chapter III) High anteversion at a certain age is associated with relative inward rotation of the condyle of the knee and low anteversion with outward rotation The results shown in fig 26 are in line with this association and suggest a method of screening The position of the condyle of the knee with the patient in the supine position with the pelvis horizontal can be determined by fluoroscopy If there is an obvious difference between the inclinations of the condylar tangents, marked torsion in the fracture is usually present Complete radiological measurement of the angle of anteversion should be carried out If on the other hand, the inclinations of the condyles of the knees are found by fluoroscopy to be essentially symmetric torsion is unlikely to be present and further radiological investigation can be avoided

Conclusions

Torsion in fractures of the femoral shaft in children treated by traction have been evaluated by radiological measurement of anteversion The clinical and subjective symptoms have then been compared with the torsion

1 Outward torsion of the distal fragment is more common than inward torsion
2 In cases with outward torsion a concomitant moderate varus angulation was often found
3 A method of screening is proposed for determining whether concomitant torsion is present in the fracture in cases with subjective symptoms and gait disturbances

GENERAL DISCUSSION

A general computer based method for determination of anatomical angles from roentgenograms was developed This method is especially designed for determination of anteversion and inclina tion of the femoral neck In this investigation a MIMER III apparatus was used but measure ments can be performed with similar devices In principle the measurement set up is identical to that described by Norman (1969) The x ray exposures are performed with the child in a con stant supine position and the lower leg hanging freely Three films are exposed for each leg – a frontal and a lateral view of the hip and a third view of the knee The main difference from Nor man s method is the use of a computer in the processing of the measured data from the films By the three films the orientation of the femur is defined relative to a coordinate system From co-ordinates on the films of the axes and points of the femur the angles are calculated by mini com puter The computer program (ANTEV in FORTRAN) is based on the general principles for central projection In contrast to all other previously described methods the present computer ized method does not presuppose an exactly defined position of the patient

The first comparison between different principal methods for the determination of anteversion with regard to comparative accuracy and reproducibility as well as the radiation dose to the gonads has recently been presented by Ruby et al (1979)

They made experiments in models and evaluated the results in clinical measurements Three methods were compared The fluoroscopic (Rogers 1934) the biplanar (Ryder & Crane 1953) and the axial (Dunn 1952) In clinical use the accuracy of measurement expressed as the standard error (SD) was found to be within ± 5° for all three methods They recommended the biplanar method because it was also easy to use in children with spasticity and this method was found to give the least radiation to the gonads Another similar biplanar method was introduced by Ripp stein (1955)

The Rippstein and the Ryder–Crane methods are performed in essentially the same way The only difference is the abduction for the second projection (Rippstein 20° Ryder–Crane 30)
Two films are exposed

1 AP projection of the hips in neutral position
2 AP projection of the neutrally rotated hips in a position of 90° flexion and 20° or 30° of abduction (γ)

In the two films the projection CD' of the true inclination CD and the projection AV of the true anteversion AV are constructed and measured (fig 28) The true angle of anteversion is then calculated from the formula

$$\tan(AV) = \tan(AV) \quad \frac{\cos(CD - 90 - \gamma)}{\cos(CD - 90)}$$

Rippstein used a conversion table based upon this formula

For a correct understanding of the values achieved in clinical use the standard error of the measuring method must be considered The errors in clinical practice must exceed the experi mental and theoretical limit

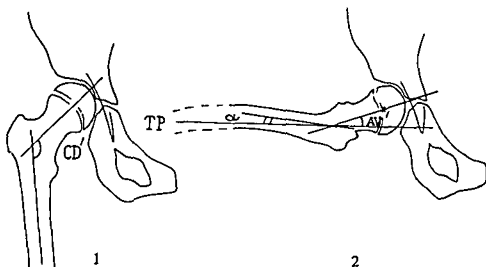


Fig 28 1 Frontal projection of the right hip 2 Projection of the right hip after flexion and abduction. The projected angle of the inclination (CD) The projected anteversion (A V') Transverse plane (TP) The angle between the proximal shaft of the femur and the transverse plane (α)

Various factors contribute to the final error of the method

A Construction and measurement of angles on the films

B Orientation of the patient e g

1 *Asymmetric positioning*

2 *Inexact abduction of the legs.*

3 *Determination of the plane of reference at the knees*

C Instability of the x ray apparatus

The influence of errors in A and B upon the accuracy of measurement of the biplanar methods can be estimated theoretically

Theoretical estimation of errors

Construction and measurement of angles on the films

On the assumption that the patient is symmetrically positioned according to the definition for the biplanar methods above a theoretical calculation of errors can be performed in the following way

By applying the Gaussian formula for propagation of errors

$$|\delta AV|^2 = \sum_{i=1}^{3} \left(\frac{\partial AV}{\partial V_i}\right)^2 (\delta V_i)^2$$

$V_1 = AV \quad V_2 = CD \quad V_3 = \gamma$ (abduction) to the formula for AV above partial errors from these variables

$$\frac{\partial AV}{\partial AV}\ \delta AV \qquad \frac{\partial AV}{\partial CD}\ \delta CD \qquad \frac{\partial AV}{\partial \gamma}\ \delta\gamma$$

and the total error δAV can be calculated from errors in the 3 variables δAV δCD and $\delta\gamma$ respectively

In the calculations an error of 1 ($\delta AV = \delta CD = \delta\gamma = 1°$) has been assumed for the 3 variables Five measurements according to the Rippstein method performed and illustrated with roentgenograms by Cyvin (1977) were used by the present author for the calculations representing high medium and low anteversion AV (table 14)

Table 14 Results (degrees) of 5 measurements with the Rippstein method ($\delta AV' = \delta CD = \delta\gamma = 1$ assumed) Calculated partial errors $\frac{\partial AV}{\partial AV'}$ $\frac{\partial AV}{\partial CD}$ $\frac{\partial AV}{\partial \gamma}$ and the total error δAV are given in the table.

AV	AV	CD	$\frac{\partial AV}{\partial AV}$ 1	$\frac{\partial AV}{\partial CD}$ 1	$\frac{\partial AV}{\partial \gamma}$ 1	δAV
67	43	168	0 72	1 11	0.57	1 44
63	48	158	0 82	0 55	0 44	1 67
38	28	148	1 17	0 40	0.38	1 30
25	20	136	1 20	0 21	0 19	1 23
17	13	141	1.31	0 18	0 17	1.33

An error in the variables AV CD' and γ of 1° gives a theoretical error $\delta AV \leqslant 1\ 5 - 2°$ in the anteversion AV The sensitivity is greatest to an error in AV An error in AV of 1° gives an error of about 1 $\left(\frac{\partial AV}{\partial AV}\ 1\right)$ in all cases

The sensitivity to CD and abduction is smaller than for AV The sensitivity to these variables is most marked in high anteversion where an error of 1° gives an error of 0 5 – 1° in the calculated anteversion AV If the error assumed in the three variables is larger the results in partial and total errors in AV are enlarged correspondingly i e an error of 3° in all the 3 variables makes the values in the table 3 times larger

When the anteversion is high unreliable results have been found by Elsasser & Walker (1973) who hold that the formula for AV is not precise for high anteversions As a result of the theoretical considerations above this opinion can be modified The formula is correct but can be sensitive to the variables measured

The computerized method for determination of angles presented in chapter I is a similar biplanar method The rotation of the x ray tube for the lateral exposure of the hip corresponds to an abduction $\gamma = 90$ Although the computerized method uses coordinates instead of angles on the films the sensitivity of the calculated anteversion and inclination to errors in construction and measurement on the films as found theoretically in chapter I are comparable to the sensitivity of the biplanar methods discussed

In order to relate the results obtained by theoretical calculations to experimental and clinical results for the biplanar methods it is necessary first to estimate realistic values of errors in the measured variables AV and CD and secondly to take into account other sources of errors not accounted for in the formula for AV

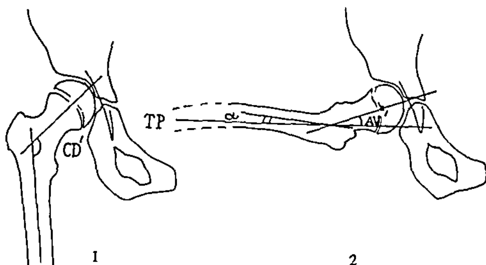


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$V_1 = AV$ $V_2 = CD$ $V_3 = \gamma$ (abduction) to the formula for AV above,partial errors from these variables

$$\frac{\partial AV}{\partial AV} \quad \delta AV \qquad \frac{\partial AV}{\partial CD} \quad \delta CD \;, \; \frac{\partial AV}{\partial \gamma} \quad \delta\gamma$$

determination of the inclination of the condyles by fluoroscopy According to the results in chapter I the plane of reference can be determined with an accuracy of about ± 0 5 – 1°
Measurement relative to well-defined planes of reference at the knee has contributed to a better understanding of the variation of anteversion during childhood (chapter III)

The sources of error discussed including the instability of the x ray apparatus add to the final result given by the Gaussian formula for propagation of errors A standard error of at least 5 therefore seems reasonable when using a biplanar method clinically which is in accordance with the values found by Ruby et al

Interpretation of clinical measurements

The evaluation of a change in anteversion is usually based on a comparison with the contra lateral side assuming an original symmetry in normal individuals With a standard error of 5° the SD of differences in anteversion between normal right and left hips is SD = $\sqrt{5^2 + 5^2} \approx 7°$ and 2 SD ≈ 14° Such differences were found by Ruby et al when they measured normal hips with the biplanar method The largest difference was 16 No statistically significant asymmetry was found between normal right and left hips which is in accordance with our results (chapter III) In the follow up study of CDH (chapter IV) the possibilities of symmetrical or asymmetrical development of anteversion have been discussed

Torsion can be measured in femoral fractures the torsion being defined as the difference in anteversion between the nonfractured and the fractured sides (chapter V)

Benum et al (1979) proposed that a difference of 5° in anteversion between the hips could in dicate a torsion in the previously fractured femur The theoretical calculations and the experi ments presented by Ruby et al demonstrate that a difference of 5° with the biplanar methods is too small to state that torsion exists

Torsion after previously traction treatment of femoral shaft fractures has also been studied by Piroth & Bliesener (1977) These authors also used the Rippstein method A difference of up to 10 was regarded as within normal Outward torsion of the distal fragment was the rule in their investigation This is in agreement with the results presented in chapter V

The inconsistent interpretations of the results in clinical measurements are probably one expla nation for the relatively large number of methods published in this field of orthopedic radio logy New methods for measurement of anteversion are successively proposed in order to com bine precision and simplicity

Chevrot (1976) has proposed two frontal projections of the hip with the x ray tube angulated in cranial and caudal direction along the femur which is kept in a constant position Computer programs of the trigonometric formula for this method have made it possible to choose the two angulations arbitrarily (Vanhoutte & Raeside 1978) Unfortunately as expressed by the authors the results are often significantly poorer in clinical practice than in experiments One explana tion for this difference is that the computer program used does not correct for positional errors of the femur including the plane of reference at the knee The standard error (SD) of the com puterized method presented in this study is ± 3 when measuring anteversion relative to the long ideal axis of the femur (Billing 1954) and negligibly larger when the short proximal femur is used The error of method for the inclination is ± 2 It has been possible to reduce the error of method when determining angles radiographically by using the computer program (ANTEV) which in principle makes the determinations independent of the positioning of the patient

Angles on the films can be measured approximately with an accuracy of 0 5° – 1° When lines and axes are drawn to depict the angles on the films from bone further inaccuracy is added Quite different values of CD can be achieved if the marking of the femoral shaft in the first projection is eccentric When CD is large as in case 1 (table 14) an eccentric marking yields an anteversion AV that differs several degrees from the anteversion AV calculated from the true central axis A change of CD in this case of 1° gives an error of about 0 5° in the anteversion AV

The results calculated here theoretically seem consistent with the experimental results obtained in bone models by Ruby et al with a standard error of 2 7° This standard error is of the same order in the computerized method (chapter I) However, an important difference between the methods is that the computerized one is independent of errors in orientation of the patient Such errors are inherent in the biplanar method and will therefore be discussed in the following.

Errors in orientation

Asymmetric positioning

In clinical practice inadequate position of the legs renders errors in the anteversion AV calculated (Gross & Haike 1970) As intended by the definition of the biplanar methods the femoral shafts must be symmetrically placed and parallel to the transverse plane in the second projection (fig 28) Otherwise, an error in AV will arise This error is directly reflected with the same magnitude in the calculated anteversion AV The condition of parallelism implies that the angle (α) between the proximal shaft and the transverse plane is equal on both sides

When measuring torsion in femoral shaft fractures the conditions of parallelism can be difficult to fulfill if there is an apparent deformity of the fractured femur This difficulty can be avoided if the anteversion is defined relative to the short proximal axis of the femur, which constitutes one of the sides of the angle α (fig 28) The short axis was used when studying torsion with the computerized method (chapter V) When using the biplanar methods and measuring according to this definition the short axis should be parallel to the transverse plane i e $\alpha = 0$ on both sides

Inexact abduction

Gross & Haike (1970) discussed the errors of incorrect abduction in their experimental work However they did not study the sensitivity to errors in abduction for different levels of anteversion The results in table 14 demonstrate that in high anteversion an error of the abduction (γ) of 1° gives an error of about 0 5° in the anteversion AV In clinical practice the error of (γ) is probably not less than 3° – 5° perhaps larger which means that the control of abduction is of importance

Determination of the plane of reference at the knee

The prerequisite in the use of the Rippstein or the Ryder–Crane methods is that there is no rotation of the femoral condyles when the position of the legs is shifted between the two exposures This assumption has not been tested in the methodological studies A possible rotation between the positions is a further source of error

This kind of error is eliminated when using the method described by Norman (1965) as well as the present method in which the femur is kept in a constant position As advocated by Norman (1969) all measurements of anteversion must be performed relative to a well defined plane of reference Such a well defined plane is the tangential plane to the dorsal parts of the femoral condyles and parallel to the long femoral axis The inclination of this tangential plane can be determined by fluoroscopy (Norman 1969) The computerized method in this study includes

determination of the inclination of the condyles by fluoroscopy According to the results in chapter I the plane of reference can be determined with an accuracy of about ± 0 5° – 1 Measurement relative to well-defined planes of reference at the knee has contributed to a better understanding of the variation of anteversion during childhood (chapter III)

The sources of error discussed including the instability of the x ray apparatus add to the final result given by the Gaussian formula for propagation of errors A standard error of at least 5° therefore seems reasonable when using a biplanar method clinically which is in accordance with the values found by Ruby et al

Interpretation of clinical measurements

The evaluation of a change in anteversion is usually based on a comparison with the contra lateral side assuming an original symmetry in normal individuals With a standard error of 5° the SD of differences in anteversion between normal right and left hips is $SD = \sqrt{5^2 + 5^2} \approx 7°$ and $2\ SD \approx 14°$ Such differences were found by Ruby et al when they measured normal hips with the biplanar method The largest difference was 16 No statistically significant asymmetry was found between normal right and left hips which is in accordance with our results (chapter III) In the follow up study of CDH (chapter IV) the possibilities of symmetrical or asymmetrical development of anteversion have been discussed

Torsion can be measured in femoral fractures the torsion being defined as the difference in anteversion between the nonfractured and the fractured sides (chapter V)

Benum et al (1979) proposed that a difference of 5° in anteversion between the hips could in dicate a torsion in the previously fractured femur The theoretical calculations and the experi ments presented by Ruby et al demonstrate that a difference of 5° with the biplanar methods is too small to state that torsion exists

Torsion after previously traction treatment of femoral shaft fractures has also been studied by Piroth & Bliesener (1977) These authors also used the Rippstein method A difference of up to 10 was regarded as within normal Outward torsion of the distal fragment was the rule in their investigation This is in agreement with the results presented in chapter V

The inconsistent interpretations of the results in clinical measurements are probably one expla nation for the relatively large number of methods published in this field of orthopedic radio- logy New methods for measurement of anteversion are successively proposed in order to com bine precision and simplicity

Chevrot (1976) has proposed two frontal projections of the hip with the x ray tube angulated in cranial and caudal direction along the femur which is kept in a constant position Computer programs of the trigonometric formula for this method have made it possible to choose the two angulations arbitrarily (Vanhoutte & Raeside 1978) Unfortunately as expressed by the authors the results are often significantly poorer in clinical practice than in experiments One explana tion for this difference is that the computer program used does not correct for positional errors of the femur including the plane of reference at the knee The standard error (SD) of the com puterized method presented in this study is ± 3 when measuring anteversion relative to the long ideal axis of the femur (Billing 1954) and negligibly larger when the short proximal femur is used The error of method for the inclination is ± 2 It has been possible to reduce the error of method when determining angles radiographically by using the computer program (ANTEV) which in principle makes the determinations independent of the positioning of the patient.



Karl Friedrich Gauss

SUMMARY

The object of this investigation has been

to elaborate a method for accurate determination of anatomical angles from roentgenograms using a computerized technique and

to apply this method when measuring the anteversion and inclination of the femoral neck in children

First the limits of accuracy of measurement in this type of measurements i e accuracy of measurement when determining angles from roentgenograms without any introduced indicator was investigated A theoretical analysis of the general principles for determination of angles from roentgenograms has been performed By the use of computer technique a practical method for determination of anatomical angles from roentgenograms has been evaluated and established No exactly defined position of the object to be measured is required In this study especially the anteversion and inclination of the femoral neck have been investigated but the method is general and is directly applicable for determination of other anatomical angles in the body In the present investigation a Mimer III apparatus (Siemens Elema) was used but the method can be performed with similar devices

In order to measure the angles of the hip the child is placed on the table lying supine with the actual lower leg hanging freely over the edge of the table Three films are exposed

1 A frontal view of the hip
2 A lateral " "
3 A lateral view of the knee after translation of the x ray tube and the film

From the coordinates on the films of the anatomical landmarks and axes of the femur different defined angles can be calculated simultaneously The calculations have been performed using a minicomputer with the computer program ANTEV in FORTRAN

When measuring anteversion the accuracy is ± 3° (SD) and for inclination ± 2° (SD) The angles have been defined relative to the long ideal axis of the femur

All measurements of anteversion must be performed relative to a well defined plane of reference at the knee Two such planes have been studied

1 The frontal plane i e the horizontal plane in supine position.
2 The tangential plane to the dorsal parts of the femoral condyles parallel to the long axis *of the femur*

The inclination of the tangential plane to the femoral condyles has been determined by fluroscopy In fluoroscopy it is possible to determine the tangential plane to the femoral condyles with an accuracy of about ± 0 5° – 1

The measurement of anteversion relative to a well defined plane of reference has contributed *to* a better understanding of the age-dependent change of anteversion during child*hood*

In young normal children there is a relative outward rotation of the femoral *condyles of the neu*trally rotated femur In adolescense this rota*tion is shifted* to an inward rotation *This means* that the anteversion towards the frontal plane i e the functional *anteversion* diminishes with growing age The anatomical anteversion i e the angle of the femoral neck towards the *tangent*



Karl Friedrich Gauss

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ial plane of the femoral condyles does not diminish with age to such a degree as has been reported in previous studies

Only in girls does the anatomical anteversion, defined as the angle between the axis of the femoral neck and the tangential plane to the femoral condyles, diminish significantly during childhood

Another observation of biomechanical interest is the tendency to compensate for high anatomical anteversion at a given age with a relative inward rotation of the femoral condyles, and the opposite when the anteversion is low

A well defined group of children with congenital dislocation of the hips (CDH), treated with a von Rosen splint in the neonatal period was investigated at the age of 6 – 9 years The anteversion and inclination in the hips of these children as a group appeared to be within normal limits These results are at variance with reports after Frejka treatment Follow up studies after such treatment have revealed remaining high anteversion in a number of children

Torsion in healed femoral shaft fractures in children treated with traction was also measured Outward torsion was the rule in the present series The maximum outward torsion did not exceed 30° A screening method has been proposed in order to judge if torsion is present or not If the inclinations of the femoral condyles in fluoroscopy are mainly symmetric further radiological investigations can be avoided as a torsion deformity is unlikely to be present in the fracture If the inclinations of the femoral condyles are asymmetric and differ more than 3°, a torsion may be present and further radiological investigation must be performed in order to determine the degree of torsion

In the closing general discussion the principal differences between conventional biplanar methods and the present computerized method were studied The sources of errors in biplanar methods type Rippstein, were analyzed theoretically A major restriction when using these methods is that the patient to be measured must be placed in a well defined position relative to the axes of projections These conditions are difficult to fulfill in clinical practice Such conditions are not required with the present computerized method which enables more precise determination of anatomical angles

Elsasser U & Walker N (1973) Zur Bestimmung der Torsion des Schenkelhalses Z Orthop 111 926–933
Eriksson U James U & Wikstrom G (1970) The angle of anteversion and the neck-shaft angle in children – a roentgenological and clinical study Acta Soc Med Ups 75, 229–240
Fabry G Mc Ewen G D & Shands A R (1973) Torsion of the femur A follow up study in normal and abnormal conditions J Bone Jt Surg 55 A 1726–1738
Fellander M Gladnikoff H & Jacobsson E (1970) Instability of the hip in the newborn Acta orthop scand Suppl. 130 36–54
Fredensborg N (1975) Congenital dislocation of the hip Discertation University of Lund
Frejka B (1941) Praventation der angeborenen Huftgelenkluxation durch das Abductions polster Wien med Wschr 91 523–524
Gage J Winter R.B (1972) Avascular necro is of the capital femoral epiphysis as a complication of closed reduction of congenital dislocation of the hip J Bone Jt Surg 54 A 373–388
Gibson R.D (1967) Anteversion of the femoral ne k A method of measurement Australas. Radiol 11 163–169
Gore D R. (1974) Iatrogenic avascular necrosis of the hip in young children J Bone Jt Surg 56 A 493–502
Gross F & Haike H (1970) Bestimmung der Genaugkeit und Fehlerquellen des Rippsteinsch en Verfarens zur Messung der Antetorsion des coxalen Femurendes Arch orthop Unfall Chir 67 234–243
Hamacher P (1974) Rontgenologische Normalwerte des Huftgelenkes CCD-Winkel und AT Winkel Orthop Praxis 10 23–28
Hansson G Romanus B (1975) Medfödd höftledsluxation – aktuella problem kring diagnostik och behandling Symposium vid Sv lakaresallskapets riksstamma i Stockholm
Heinrich R. Hennig A & Thiel K.W (1968) Röntgenologische Untersuchung zur umwegigen Entwicklung der Femurtorsion bei huftgesunden Kindern Z Orthop 104 555–561
Hiertonn T James U (1968) Congenital dislocation of the hip Experiences of early diagnosis and treatment J Bone Jt Surg. 50 B 542–545
Hubbard D D & Staheli L.T (1972) The direct radiographic measurement of femoral torsion using axial tomography Clin Orthop 86 16–20
Johansson S (1934) Roentgenological studies of the anatomy of the proximal end of the femur Acta orthop scand 5 358–380
van Joost M C & Gastkemper R.J B (1972) Malrotation after femoral shaft fractures Arch Chir Neerland XXIV–II 101–115
Kingsley P C & Olmsted K L. (1948) A study to determine the angle of anteversion of the neck of the femur J Bone Jt Surg 30 A 745–751
Kootstra G (1973) Femoral shaft fractures in adults Van Gorcum Assen
Konig G (1972) Eine praktische Methode zur röntgenologischen Bestimmung des Antetorsions- und Kollodiaphysenwinkels Z Orthop 110 76–82
König G & Schult W (1973) Der Antetorsions- und Schenkelhalsschaftwinkel des Femur Probleme der rontgenologischen Bestimmung und der operativen Korrektur Ferdinand Enke Verlag Stuttgart
Laage H Barnet J C Brady J.M Dulligan P J jr Fett H C jr Gallagher T F & Schneider B A (1953) Horizontal lateral roentgenography of the hip in children Preliminary report J Bone Jt Surg. 35 A 388–398

References

Alvik, I (1950) Causes and therapy of arthrosis of hip Nord med 44, 1951–1954

Alvik, I (1960) Increased anteversion of the femoral neck as a sole sign of dysplasia coxae Acta orthop scand 29 301–306

Backman S (1957) The proximal end of the femur Acta Radiol Suppl 146

Badgley, C E (1943) Correlation of clinical and anatomical facts – leading to a conception of the etiology of congenital hip dysplasis J Bone Jt Surg 25, 503–523

Barlow T G (1962) Early diagnosis and treatment of congenital dislocation of the hip J Bone Jt Surg 44–B 292–301

Beals, R K (1969) Developmental changes in the femur and acetabulum in spastic paraplegia and diplegia Dev Med Child Neurol 11, 303–313

Benum P, Ertresvåg, K & Høiseth, K (1979) Torsion deformities after traction treatment of femoral fractures in children Acta orthop scand 50 87–91

Bernageau J & Bourdon R (1968) Mesure directe tomographique de l angle de declination (anteversion) du col femoral chez l adulte Rev Rhum 35 196–200

Billing L (1954) Roentgen examination of the proximal femur end in children and adolescents Acta Radiol Suppl 110

Bjerkreim I (1974) Congenital dislocation of the hip joint in Norway Acta orthop scand Suppl 157

Brattstrom H (1962) Two sources of error in measurement of the anteversion angle of the femur Acta orthop scand 32 252–256

Budin E & Chandler M E (1957) Measurement of femoral neck anteversion by a direct method Radiology 69 209–213

Chevrot A (1976) Technique radiologique simplifiée dans la mesure de l angle d anteversion du femur et de l angle cervico diaphysaire J Radiol Electrol Med Nucl 57 545–548

Crane, L (1959) Femoral torsion and its relation to toeing in and toeing out J Bone Jt Surg. 41 A 421–428

Cyvin K B (1977) A follow-up study of children with instability of the hip joint at birth Acta orthop scand Suppl 166

Dooley, B.J (1964) Osteocondritis in congenital dislocation and subluxation of the hip J Bone Jt Surg 46 B 198–203

Dooley E A, Caldwell C E jr & Glass G A (1938) Roentgenography of the femoral neck A technique to obtain true lateral and antero posterior views Amer J Roentgen 39 834–837

Drehmann G G (1909) Streitfragen aus dem Gebiet der angeborenen Huftverrenkung Dtsch Ges Orthop Chir Kongr – Z Orthop Chir 11, 220–233 (1903)

Dunlap K Shands A R jr Hollister L C jr, Gaul J S & Streit H A (1953) A new method for determination of torsion of the femur J Bone Jt Surg 35 A 289–311

Dunn D M (1952) Anteversion of the neck of the femur A method of measurement J Bone Jt Surg 34 B 181–186

Edgren W & Laurent L E (1956) A method of measuring the torsion of the femur in congenital dislocation of the hip in children Acta Radiol 45 371–376

Edholm P (1966) Anatomic angles determined from two radiographic projections Instrument description and measurement techniques Acta Radiol Suppl 259

Edholm P (1972) Nomogram for measuring the anteversion angle and angulations from roentgenograms Acta Radiol 12 856–864

Ruby L. Mohnder A.M. O Connor I & Upendra P (1979) Anteversion of the femoral neck. Comparison of methods of measurements in patient J Bone Jt Surg 61 A 46–51
Ryder C T & Crane L (1953) Measuring femoral anteversion The problem and a method J Bone Jt Surg 35 A 321–328
Salter R B Kostuik J & Dallas S (1969) Avascular necrosis of the femoral head as a complication of treatment for congenital dislocation of the hip in young children – a clinical and experimental investigation Canad J Surg 12 44–61
Samilson R L (1975) In orthopaedic aspects of cerebral palsy Clinics in Developmental Medicine 52–53
Schultz P.J (1924) Die Darstellung des Torsionswinkels vom Femur mit Hilfe von Rontgen strahlen Z Orthop Chir 44 325–334
Shands A R & Steele M K (1958) Torsion of the femur A follow up report on the use of the Dunlap method for its determination. J Bone Jt Surg 40 A 803–816
Strasser H (1917) Lehrbuch der Muskel und Gelenkenmechanik Band III Die untere Extremitat Julius Springer Verlag Berlin.
Teinturier P & Dechembre H (1968) Etude de l antéversion de la hanche de l enfant Rev Chir orthop 54 545–551
Vanhoutte J.J Raeside D E (1978) A generalization of Chevrot s Method for determining anteversion and cervico-diaphyseal angles Radiology 128 251–252
Vontobel V Genton N & Schmid R (1961) Die Spatprognose der kindlichen dislozierten Femurschaftfraktur Helv chir Acta 28 655–670
Walker C (1971) Problems in the early recognition of congenital hip dislocation Brit med J 3 147–148
Weber B G (1969) Fractures of the femoral shaft in childhood Injury 1 65–68
Wiberg G (1939) Studies on dysplastic acetabula and congenital subluxation of the hip joint Acta Chir scand Suppl 59
Williamsson J (1972) Difficulties of early diagnosis and treatment of congenital dislocation of the hip in the Northern Ireland J Bone Jt Surg 54 B 13–17
Yano S & Sawada M (1975) Rotationsfehler nach kindlichen Femurschaftfrakturen. Z Orthop 113 119–129
Zenker H (1972) Zur Indikation und Technik korrigierender Osteotomie im Schaftbereich langer Rohrenknochen Arch orthop Unfall Chir 74 205–223
Zippel H (1971) Untersuchungen zur Normalentwicklung der Formelemente am Hüftgelenk im Wachstumsalter Beitr Orthop 18 255–270

Lange F & Pıtzen, P (1921) Zur Anatomıe des oberen Femurendes Z Orthop Chır 41 105–134

von Lanz, T & Wachsmuth W (1938) Praktısche Anatomıe Eın Lehr und Hılfsbuch der ana tomıschen Grundlagen arztlıchen Handelns Sprınger Verlag Berlın

von Lanz, T (1951) Uber umwegıge Entwıcklungen am menschlıchen Huftgelenk Schweız med Wschr 81, 1053–1056

Leger, W (1952) Zur Torsıonsbestımmung des Schenkelhalses Z Orthop 81, 583–592

Lıttle K Pımm L H Trueta J (1960) Osteochondrıtıs ın congenıtal dıslocatıon of the hıp – a clınıcal and radıographıc study Acta orthop scand 29 218–236

Magıllıgan D J (1956) Calculatıon of the angle of anteversıon by means of horızontal lateral roentgenography J Bone Jt Surg 38 A, 1231–1246

Metz, R (1964) Eın Beıtrag zur vereınfachten Bestımmung des Antetorsıonwınkels am Schen kenhals Arch Orthop Unfallchır 56 85–90

Morscher, E (1967) Development and clınıcal sıgnıficance of the anteversıon of the femoral neck Reconstr Surg Traumat 9 107–125

Muller, M E (1967) Posttraumatısche Achsenfehlstellungen an den unteren Extremıtaten Hans Huber Verlag, Bern und Stuttgart

Muller, M E (1971) Dıe Huftnahen Femurosteotomıen, 2 Auflage, Georg Thıeme Verlag Stutt gart

Nıcod, L (1967) Posttraumatısche Achsenfehlstellungen an den unteren Extremıtaten Hans Huber Verlag Bern und Stuttgart

Norman O (1965) Beskrıvande geometrı som hjalpmedel vıd bestamnıng av collum antever sıonsvınkeln collum dıafysvınkeln samt fraktur vınkeln Nord Med 73 446–447 och Nord Med 74 119

Norman O (1966) Rontgenologısk bestamnıng av collumanteversıonsvınkeln och dess praktıska tıllampnıng Nord Med 75 318–319

Norman O (1969) Betydelsen av anatomıska defınıtıoner av collum femorısaxeln för bestam nıng av anteversıonsvınkeln Foredrag vıd Nordısk Ortopedısk Forenıngs mote ı Helsıngfors

Norman O (1969) Matnıng av collum anteversıonsvınkeln En prıncıpıell dıskussıon Nord Med 82 991–992

Norman, O (1978) Personal communıcatıon

Ortolanı, M (1937) Un segno poco noto e sua ımportanza per la dıagnosı precose dı prelussa zıone congenıta Pedıatrıa (Napolı) 45 129–136

Palmén, K (1961) Preluxatıon of the hıp joınt Acta paedıat scand Suppl 129

Pıroth P & Blıesener I A (1977) Rotatıonsfehlstellung nach konservatıver Behandlung kınd lıcher Oberschenkelschaftfrakturen Z Kınderchır 20 172–180

Probst F (1977) Personal communıcatıon

Reynolds G T & Herzer F E (1959) Anteversıon of the femoral neck Clın Orthop 14 80–89

Rıppsteın J (1955) Zur Bestımmung der Antetorsıon des Schenkelhalses mıttels zweıer Ront genaufnahmen Z Orthop 86 345–360

Rogers S.P (1931) A method for determınıng the angle of torsıon of the neck of the femur J Bone Jt Surg 13 821–824

Rogers S P (1934) Observatıons on torsıon of the femur J Bone Jt Surg 16 284–289

von Rosen S (1956) Early dıagnosıs and treatment of congenıtal dıslocatıon of the hıp joınt Acta orthop scand 26 136–155

Ruby L. Mohlnder A.M O Connor I & Upendra P (1979) Anteversion of the femoral neck. Comparison of methods of measurements in patient J Bone Jt Surg 61 A 46–51
Ryder C T & Crane L. (1953) Measuring femoral anteversion The problem and a method J Bone Jt Surg. 35 A 321–328
Salter R.B Kostuik J & Dallas S (1969) Avascular necrosis of the femoral head as a complication of treatment for congenital dislocation of the hip in young children – a clinical and experimental investigation. Canad J Surg 12 44–61
Samilson R.L. (1975) In orthopaedic aspects of cerebral palsy Clinics in Developmental Medicine 52–53
Schultz P.J (1924) Die Darstellung des Torsionswinkels vom Femur mit Hilfe von Rontgen strahlen Z Orthop Chir 44 325–334
Shands A R & Steele M.K (1958) Torsion of the femur A follow-up report on the use of the Dunlap method for its determination. J Bone Jt Surg 40 A 803–816
Strasser H (1917) Lehrbuch der Muskel und Gelenkenmechanik. Band III Die untere Extremitat Julius Springer Verlag Berlin.
Teinturier P & Dechembre H (1968) Etude de l antéversion de la hanche de l enfant Rev Chir orthop 54 545–551
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Vontobel V Genton N & Schmid R. (1961) Die Spatprognose der kindlichen dislozierten Femurschaftfraktur Helv chir Acta 28 655–670
Walker G (1971) Problems in the early recognition of congenital hip dislocation. Brit med J 3 147 148
Weber B G (1969) Fractures of the femoral shaft in childhood Injury 1 65–68
Wiberg G (1939) Studies on dysplastic acetabula and congenital subluxation of the hip joint Acta Chir scand Suppl 59
Williamsson J (1972) Difficulties of early diagnosis and treatment of congenital dislocation of the hip in the Northern Ireland. J Bone Jt Surg. 54 B 13–17
Yano S & Sawada M (1975) Rotationsfehler nach kindlichen Femurschaftfrakturen. Z. Orthop 113 119–129
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RIK HUISKES

Some Fundamental Aspects of Human Joint Replacement

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From the Laboratory for Experimental Orthopaedics Department of Orthopaedics University of Nijmegen in collaboration with the Division of Applied Mechanics, Department of Mechanical Engineering Eindhoven University of Technology The Netherlands

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Some parts of the work described in this book have been presented at conferences previously

With respect to section II
- First European Conference on Evaluation of Biomaterials, Strasbourg, France, 1977 (Huiskes *et al*, 1977)*
- European Society of Biomaterials Conference, Brussels, Belgium, 1978 (Huiskes and Slooff, 1978)
- 24th Annual Meeting Orthopedic Research Society, Dallas Texas, 1978 (Huiskes and de Wijn, 1978)
- 25th Annual Meeting Orthopedic Research Society San Francisco, California, 1979 (Huiskes, 1979)
- Third International Conference on Plastics in Medicine and Surgery, Enschede, the Netherlands, 1979 (Huiskes *et al*, 1979)

With respect to section III
- 29th ACEMB Boston, Massachusetts 1976 (Huiskes *et al*, 1976)
- VIth International Congress of Biomechanics Copenhagen, Denmark, 1977 (Huiskes *et al*, 1977)
- *Deuxieme Congres de la Societe de la Biomécanique* Liege, Belgium, 1977 (Huiskes and Slooff, 1977)
- 24th Annual Meeting Orthopedic Research Society, Dallas, Texas 1978 (Huiskes and Slooff, 1978)
- First Conference of the European Society of Biomechanics Brussels Belgium, 1978 (Huiskes 1978)
- Pauwels Symposium Biomechanik in Orthopadie und Traumatologie, Berlin, BRD, 1979 (Huiskes and Slooff, 1979)
- Second Conference of the European Society of Biomechanics, Strasbourg France, 1979 (Huiskes 1979 Huiskes and de Wijn, 1979)
- VIIth International Congress of Biomechanics, Warshaw, Poland 1979 (Huiskes and Slooff 1979)

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Voor Marianne en Sabine

en voor mijn ouders

"To a scientist a mathematical model is as a stethoscope to a physician or a trowel to a bricklayer The model is an image of reality, an abstraction, which touches upon reality in such a manner as to render some if its characteristics visible It is the expedient relating complex systems to more trivial and simple systems, which last then represent the former The development of models enables us to compensate for the limits of our imagination and descriptive abilities, by refraining from details and concentrating on the essentials, the complex reality becomes surveyable, controllable and comprehensible"

J P Hooft (1979)
De onderzoeker aan de zoom van de praktijk,
De Ingenieur, no 16, Jaargang 91, p 289 (translation)

CONTENTS

INTRODUCTION

Artificial joint replacement the fixation of an artificial device to substitute for the kine matic and dynamic function of human joints has become a widely accepted treatment in orthopedic surgery against advanced joint arthritis and disabling effects of post traumatic conditions and resective bone tumor surgery The performance of such a technical structure in the muscelo skeletal system is quite complicated and has many biological and mechanical aspects The long term survival of the fixation is not trivial and it is the aim of those con cerned with these treatments to create the optimal conditions both from the biological and mechanical points of view

The need for better understanding of the complicated mechanical aspects of joints and joint replacements has given rise to collaboration between orthopedic surgeons and engineers in the fields of biomechanics and biomaterials In orthopedic biomechanics a field fairly recent ly evolved, the mechanical functions and structure of normal bones joints and connective tissues as well as the mechanical interaction between bones and artificial implants are studied The purpose of these investigations is to develop a better understanding, quantitatively, of the mechanical aspects of the muscelo skeletal system and provide criteria on the mechanical aspects of diagnostic methods and surgical interventions, for example artificial joint fixation The investigations described in the following chapters are the results of such interdisciplinary ventures carried out in the Laboratory for Experimental Orthopaedics at the Department of Orthopedics of the University of Nijmegen, where an Orthopedic Biomechanics section was set up about 5 years ago, in collaboration with the Applied Mechanics Division of the Depart ment of Mechanical Engineering at the Eindhoven University of Technology The studies were concerned with artificial joint loosening problems A more specific description of the objects of the studies will be given at the end of this introduction where the contents and the sequence of the subjects presented will also be outlined

Since this area of activities is rather new to engineering disciplines, especially in the Nether lands, pains have been taken to sketch out a general outline of artificial joint replacement as an orthopedic treatment its occurrence rate its problems and the contributions that engineers can possibly make, part of this will be discussed in the remainder of this introduc tion

Although not often recognized as such, arthritis is one of the major disabling diseases in our society Some statistical data on arthritis in the U S A were cited by Chao (1976) in 1973 an Arthritis Foundation study showed that approximately 20 million Americans of whom more than 75% are between 45 and 65 years of age, have symptoms of arthritis In 1969, aged patients spent more than 70 million days in bed and employed people lost more than 14 million working days because of arthritis

Although not a cause of high mortality arthritis inflicts severe pain and functional disability The economic consequences of this disease in terms of social security manpower loss and health care are substantial

Since the development of artificial joints made its dramatic breakthrough in the early sixties many patients with severe arthritis were successfully operated and now function normally and free from pain This development is illustrated in fig 1 (Gschwend 1976) giving the number of artificial hip replacements and other treatments of arthritis as carried out in Swiss clinics

Although the success of artificial joint replacement dates back relatively few years the development started a long time ago Excellent reviews of the history in this respect have been given by Walker (1977) and Huggler and Schreiber (1978)

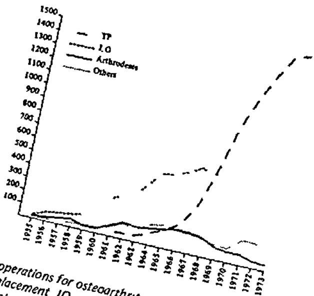


fig 1 Number of hip operations for osteoarthritis in 9 Swiss orthopedic clinics 1955 1973 TP total hip replacement IO intertrochanteric osteotomy (where anatomical proportions of the joint are changed) arthrodeses. Stiffening of the joint (reproduced with permission of Gschwend 1976)

Due to the important kinematic and load bearing function of the hip and the high number of patients suffering from degenerative hip diseases the first and main efforts in artificial joint replacement were focussed on this joint
Starting early this century many methods of treatment and materials were tried More-or less successful trials have been reported by Smith Petersen (1939) Moore and Bohlman (1943) and Judet (1954) among others In their different replacement concepts only one bone component of the joint was replaced in function with the normal cartilage of the other component Wiles (1957) reported on operations on patients using a total hip replace ment where both sides of the joint were replaced by a femoral and an acetabular component respectively
Although surgical procedures in general became more successful in the course of this century thanks to better antiseptic measures and anesthetic procedures the short and long term results of the early joint replacement trials were relatively speaking rather poor mainly because of the lack of an adequate fixation These circumstances changed after Charnley (1960) introduced the use of acrylic cement as space filling fixation material and his concept of low friction total hip arthroplasty replacing the acetabular component of the joint with a plastic cup and the femoral component with a metal endoprosthesis
Acrylic cement or bone cement is a cold-curing plastic It consists of a mixture of poly methylmethacrylate and monomethylmethacrylate and is inserted in the bone in a doughy phase allowing the surgeon to mold it between the implant and the bone After a few minutes it polymerizes to a solid substance Although the acrylic cement sticks neither to the bone nor to the implant the space filling capacities guarantee a smoothening of the load distribution and a firm placing of the implant Fig 2 shows a schematic illustration of a cemented Charnley hip prosthesis
The results reported by Charnley (1972) were extraordinarily good and following this break through total hip replacements have been carried out in ever growing numbers making it one of the major surgical interventions in orthopedic clinics today

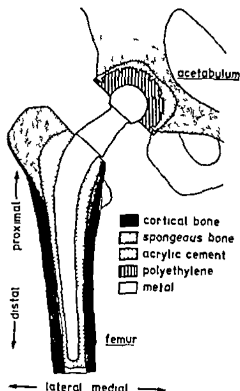


fig 2 Schematic illustration of a Charnley total hip prosthesis (acetabular and femoral component) fixated in the bone with acrylic cement Distal and proximal, medial and lateral directions are indicated

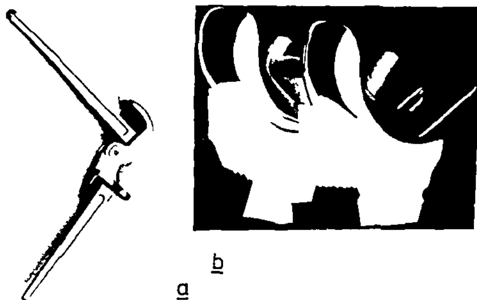


fig 3 Artificial knee joints are available in two principally different concepts, hinged and surface types Examples are (a) G U E P A R (hinged type) and (b) Geomedic (surface type)
(Reproduced with permission of v Rens and Huiskes, 1976)

Although the hip joint still receives the most attention developments have rapidly expanded to other joints Artificial hinges for the knee joint were already developed by Moeys (1954) Shiers (1954) and Walldius (1957) followed by numerous designs for knee surface replacement and other hinged joints in the nineteen seventies (fig. 3) Attention was given as early as the nineteen fifties to the elbow the shoulder and the finger joints recently followed by the ankle and wrist Several designs are now available for various joints and especially the hip and the knee are being replaced routinely in most orthopedic clinics
In the Orthopedic Department of the University of Nijmegen in 1977 artificial joint replacement was carried out in roughly 20% of all operative interventions and it accounted for approximately 30% of the total operation time 75% of the replacements were in the hip and 23% in the knee joint
Using estimates from several sources an assessment was made of the number of total joint replacements carried out annually in the U S A by Hori *et al* (1978) In their questionnaire they not only investigated the number of replacements carried out but also included the number of patients that were indicated for an artificial joint but did not receive one because in the opinion of the surgeon no reliable design was available A summary of their results is given in table I

	1972	1973	1974	1975	1976	Total	1976
			implanted				indicated
Hip	55 000	75 000	77 500	80 000	80 000	367 500	89 600
Knee	4 000	10 000	20 000	32 500	40 000	106 500	52 800
Others	2 500	3 800	6 500	8 500	10 000	31 300	33 900
Total	61 500	88 800	104 000	121 000	130 000	505 300	176 300

table I *Estimated number of joint replacements carried out annually in the U S A from 1972 to 1976 and indicated number of joint replacements in 1976 (after Hori et al 1978)*

Data with respect to the number of joint replacements carried out in the Netherlands were supplied by the Foundation for Medical Registration (table II)

Hip	7 277	Hand (wrist included)	uncertain
Knee	643	Shoulder	29
Elbow	30	Ankle	no data

table II *Number of arthroplasties (non-artificial included) carried out in 1977 in the Netherlands (source Found Med Registration Utrecht the Netherlands)*

It can be estimated that in the near future somewhere around 300 000 artificial joint replacements will be performed annually in the world If we assume an average life expectancy of the patients to be approximately 8 years (an arbitrary estimate) we find that on the average soms 2 4 million people with artificial joints will be alive

Although widely applied, artificial joint replacement is not without complications Some of these are characteristic of all major operations, others are more specific The most trouble some of these specific complications is loosening of the device, directly or indirectly caused by a variety of mechanical and biological phenomena In patient reviews it was established that the incidence of loosening rises steeply with the amount of postoperative years This has resulted in many revision and salvage operations Moreover, generally speaking, it limits the application of artificial joints to older people, the present criterion being about 55 years and over Still, the need for joint replacement in young patients is anything but negligible Presently, many efforts by scientists from medical and engineering disciplines are being put into the development of artificial joints and fixation procedures that will diminish the com plications and guarantee longer service life

The function of an artificial joint is purely mechanical, although of course the biological reactions of the bone and the soft tissues play important and complicating roles The joint has to provide for a kinematic system that accords with the kinematic characteristics of the original joint, it has to be able to stand up to the physiological joint loading and experience little wear and friction, the material should not induce undesirable tissue reactions and has to transfer the load to the bone in such a way that a rigid fixation remains intact for many years
Until very recently artificial joints were being developed more or less by trial and error' After a certain number of patients had received a specific design and a number of post operative years had passed, the patients were reviewed Based on the short and long term findings, the design was often adapted or dropped altogether Only seldom could a causative relation be established between the failures and the characteristics of the design A good design may have been rejected merely because it was inadequately implanted and a bad design may have been widely accepted only because the surgeon designer carried out the first operations exceptionally well, quite individual accomplishments perhaps not repro ducable by others Also, quite good designs may have been rejected as a whole in the past, only because minor and easily changeable details had led to complications As a result of this development, many types of prostheses are presently available for the different joints These different types can be divided into a small number of categories, within each category the differences are only those of detail If we count only the popular' types about 48 different designs of knee prostheses are available, 10 different elbow prostheses, 4 different shoulder prostheses, 6 different ankle prostheses, around 10 different finger prostheses, a few wrist prostheses and the different designs of hip prostheses available far exceed a hundred New designs, sometimes differing only slightly, are developed yearly Few objective criteria are known for a justified choice between the different makes and, if a choice is made, the orthopedic surgeon usually never finds out whether failures are due to an in adequate surgical procedure, to individual properties of the patient or to the design features

It is the object of the research work described in the following chapters to provide a more fundamental comprehension of some aspects of artificial joints and their performance in the body Two subjects of investigation have been chosen, both regarding the incidence of implant loosening First the cause of bone necrosis as usually seen directly after the opera tion in a small zone close to the acrylic cement adjoining the bone, and more specifically, the possible effect in this phenomenon of the heat developed in the acrylic cement during the polymerization process This part of the work is described in section II Second the stress distribution in the implant the acrylic cement the bone and on the contact regions of these materials as results of the physiological joint loading in relation to the strength of the components and possible mechanical failure These stress analyses are confined to intra medullary fixation systems prostheses that are fixated inside the medullar cavity of the

bones using a stem and although the methods that will be discussed and some of the results are valid for these systems in general the analyses are principally focussed on the hip endoprosthesis This part of the work is treated in section III

Although results of experiments carried out in our own laboratories as well as those publish ed in the literature will be used the approach in both areas is mainly analytical Principles of mechanics and heat conduction theory will be applied to evaluate the system behavior and the influences of the system parameters This approach is not quite common in ortho pedics and it is felt that especially in this respect the (biomechanical) engineer can make a contribution to better fundamental understanding of the bone implant structure and some of its problems

It should be understood that such a contribution to a more fundamental understanding of some phenomena was the object of the work presented and that no new device or material is envisaged although some objective quantitative guidelines for prosthesis designs and surgical procedures will result and moreover a simple method will be proposed that can be used to predict the mechanical performance of specific endoprosthesis designs in patients and hence clear the way to a more custom fit approach

The two investigations described here are not the first ventures into the problem areas nor will they be the last part of the work has been devoted to an evaluation of studies published in the literature a review of which is presented also in sections II and III respectively As the approach is uncommon in orthopedics and the methods used are of a quite complicated nature from a medical point of view the possibilities and limitations of theoretical methods are discussed to a somewhat greater extent in section I and some relevant conclusions will be discussed in more general terms in section IV

Section I also gives a more detailed characterization of artificial joints and artificial joint replacement and describes some properties of the bone implant system as far as they are relevant to the analyses presented Complications of artificial joint replacement especially prosthesis loosening will be discussed based on a review of the literature on this subject in section I too after which the objects of the investigations presented in sections II and III will be defined in more detail

REFERENCES

Chao, E Y (1976), The biomechanics of total joint replacement surgery, Geriatrics, March

Charnley, J (1972), The long term results of low friction arthroplasty of the hip performed as a primary intervention, J Bone Jt Surg 54 B 61

Gschwend, N (1976), Symposium on total postheses, clinical material and overall results, In Total hip prosthesis (Gschwend and Debrunner, eds), Hans Huber Publ , Bern, Stuttgart, Vienna

Hori, R Y , Lewis, J L , Zimmerman, J R and Compere, C L (1978), The number of total joint replacements in the United States, Clin Orthop and Rel Res , No 132, 46 52

Huggler, A H und Schreiber, A (1978), Alloarthroplastik des Huftgelenkes, Georg Thieme Verlag, Stuttgart

Judet, R (1954), Experience of hip arthroplasties by acrylic prostheses since 1946, J Bone Jt Surg 36 B, 691

Moeys, E Y (1954), Metal alloplasty of the knee joint, J Bone Jt Surg 36 A, 363

Moore, A T and Bohlman, H R (1943), Metal hip joint – A case report, J Bone Jt Surg 25 688

Rens, Th J G van and Huiskes, R (1976), De operatieve behandeling van gonarthrosis, Ned T v Geneesk 20, nr 31, p 1322

Shiers, L P G (1954), Arthroplasty of the knee, J Bone Jt Surg 36 B, 553

Smith Petersen, M N (1939) Arthroplasty of the hip A new method, J Bone Jt Surg 21 269

Walker, P S (1977), Human joints and their artificial replacements Charles C Thomas Publ , Springfield, Ill

Walldius, B (1957), Arthroplasty of the knee, using an endoprosthesis, Acta Orthop Scand Suppl 24 5

Wiles, P (1957), The surgery of the osteo arthritis hip, Br J Surg , 45 488

SECTION ONE

PROPERTIES AND COMPLICATIONS OF ARTIFICIAL JOINT REPLACEMENT

REFERENCES

Chao, E Y (1976), The biomechanics of total joint replacement surgery, Geriatrics, March

Charnley, J (1972), The long term results of low friction arthroplasty of the hip performed as a primary intervention, J Bone Jt Surg 54 B 61

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INTRODUCTION

In this section some general aspects of artificial joint replacement are described as far as deemed relevant to an understanding of the objects and results of the studies discussed in sections II and III Workers in medical as well as technical fields may encounter trivial infor mation because this section is meant to be an introduction for both Properties of the bone prosthesis system relevant for the analyses are described in chapter 1
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Although some general aspects of artificial joint replacement are discussed in this section most are focussed on the hip joint

CHAPTER ONE

CHARACTERIZATION AND PROPERTIES OF BONE IMPLANT SYSTEMS

1 1 Surgical procedure

A division can be made into intramedullary fixated implants (endoprostheses) where a prosthesis stem is fixed into the meduallary cavity and surface replacement where the implant is more or less fixated against the bone Some prostheses for instance tibial com ponents of some knee prostheses use a mixed form of fixation
In both cases parts of the bones involved in the articulation are resected When an intra medullary stem is used the medullar cavity is cleaned and reamed to some extent In this procedure a part of the vascularity system that nourishes the bone is at least temporarily disturbed especially in the diaphyseal region Presently most of the artificial joints are fixated by means of acrylic cement The two components of this cement are mixed by the surgeon during the operation The curing process starts right after the mixing procedure and takes something in the order of 5 10 minutes Still in a doughy state the cement is inserted into the medullar cavity or positioned against the bone the prosthesis is then pressed into the cement mass and held until the cement has cured to a solid mass
Especially with intramedullary fixated implants the surgeon has no complete control over the consistency and the thickness of the cement mantle Often air bone debris and blood are mixed in the cement and the distal part of the cement mass may be pushed downward into the medullar canal
It has been recognized that a syringe should be used to ensure a complete and homogeneous cement mantle (Slooff 1969)
Recently the use of an intramedullary bone plug has been advocated to enable more pressure to be put on the cement mass during insertion and prevent the distal cement mass from

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being pushed downward (Markolf and Amstutz, 1976, Oh *et al*, 1978, Krause *et al*, 1979, Weber and Stuhmer, 1979) Pulsatile water lavage before cement insertion has been advised in order to clean the bony implant bed prior to fixation of all prostheses (Narten *et al*, 1977, Halawa *et al*, 1978, Miller *et al*, 1978)
A very important part of the operation is the positioning and alignment of the prosthesis Usually this is done by visual judgement
Some complications, called preoperative complications, may occur during the operation, these include perforation of the implant through the bone, fracture of the bone injury to arteries or veins, injury to nerves, anesthetic complications, embolies and several others

1 2 Basic requirements for artificial joints

An artificial joint has to approximate as closely as possible the natural joint function for the full postoperative life span, without discomfort and complications More specifically some practical requirements can be formulated that have to be taken into account when new designs or surgical procedures are being considered

- The prosthesis and fixation materials should not induce undesirable tissue reactions, as bone necrosis or bone resorption, they should have acceptable friction and wear characteristics and not corrode
- The surgical procedure should be relatively simple and fast standardized and repro duceable, with minimal surgical trauma
- The design of the prosthesis the choice of materials, with reference to strength as well as stiffness properties should be such as to guarantee adequate mechanical performance in such a way that stress concentrations are avoided and that implant, cement, bone and the relevant interfaces are not loaded beyond their strength or fatique limits
- The implant should have a good salvage potential meaning that if the system fails, another solution remains possible Since the ultimate salvage solution is usually arthro deses, for instance this means that as little bone as possible should have to be resected
- Early mobilization sterilization of the components and reasonable manufacturing costs of the implant should all be possible

Obviously an adequate artificial joint design will always be a trade off between these different requirements A mechanical compromise that usually has to be considered is the one between requirements of range of motion and degrees of freedom (or constraints) on th one hand and of stability on the other A low constraint joint that has an extensive range of motion in other words is free to move in several directions in an extensive range will o the one hand offer little stability but on the other hand will have to transfer less loading the fixation system, hence will give less rise to mechanical loosening than a highly con ed joint with a limited range of motion

1 3 Implant shapes and materials

Artificial joints are available in a variety of types and shapes Intramedullary stems are used in different designs for all joints but the ankle The acetabular part of the hip prosthesis is surface replacement, the femoral part usually has an intramedullary stem although since recently surface replacement of the femoral head is also becoming popular (double cup prosthesis) The hinged knee prostheses are usually intramedullary fixated some of the kn

surface replacements also have intramedullary stems Finger prostheses elbow prostheses and shoulder prostheses use intramedullary fixation in all cases The artificial wrist joint is usually a surface replacement combined with a stem for both components

The configuration of the artificial joint greatly depends on the kinematic function it has to perform and the stability it has to give Three basic configurations are (e g Chao 1976) he ball and-socket design (hip shoulder) the articulating type with various degrees of reedom (knee ankle elbow wrist) the hinged types (knee finger elbow) Combinations f these basic types are also used

The designs may also vary greatly in shape and dimensions even if functionally identical A dimensional classification of about 20 popular hip joint designs was given by Walker (1977) diameters of the prosthesis femoral head vary from 22 to 48 mm neck lengths vary from 15 to 55 mm stem lengths from 93 to 180 mm and a few exceptional stems from 240 to 370 mm The stem may be strongly curved or rather straight while different kinds of cross sectional geometries are used (diamond shaped rectangular rounded-off triangular oval) Some designs use a more or less pronounced collar on the proximal side of the stem resting on the bone rim The stem is usually tapered to a greater or lesser extent

Many different implant materials have been used in the past They must be strong tough resistent to fatigue and wear tolerated by the body and processable at reasonable costs Because of the favorable friction and wear properties most designs presently use a metal component against a plastic component The metal components usually consist of high grade stainless steel cobalt chromium alloys or titanium alloys the plastic components of high density polyethylene (HDPE) or ultra high molecular weight polyethylene (UHMWP) Experiments are being carried out with ceramics Delrin and composite materials Silastic is being used in finger prostheses The femoral part of the total hip replacement is always fabricated in metal and the acetabular cup usually in plastic An extensive review of materials used for human implantation and their properties has been published by Rostoker and Galante (1979)

1 4 Loading of the joint

ly the joint loading is meant the resulting force and moment that one joint component xerts on the other and vice versa by means of their articulating contacts he kind of loading depends on the kind and intensity of the activity The loading is caused gravity forces acceleration forces muscle forces and forces due to ligament constraints Investigations of human joint loading belong to the first activities in biomechanics and date back many ages Many studies on this subject have been published and many are still being carried out A review of the relevant literature is given by Walker (1977) Since the joint forces cannot be measured directly they have to be estimated using equilibrium conditions and data from force plate studies (measuring the ground reaction force) EMG studies (electromyography giving an indication at large of muscle activity) movement studies and anthropometric measurements Promising new possibilities are those of computer simulation modeling the complete skeletal system as a kinematic chain taking the important muscle groups into account and solving the redundant problem using optimization criteria. A first effort in this direction was published by Seireg and Arvikar (1975) Although reliable data accurate in an absolute sense is not available as yet results of various studies indicate that the joint forces are much higher than sometimes assumed Brewster *et al* (1974) have calculated from force plate studies that the force in the ankle joint

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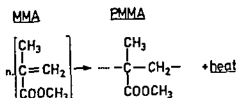


fig 1 2 Description of the polymerization reaction in which monomethylmethacrylate molecules are connected to form polymer chains

the polymerization process of the monomer starts (fig 1 2) ultimately embedding the PMMA powder into a PMMA matrix so that a solid substance remains During the polyme rization process heat is generated which has to be conducted through the adjoining materials implant and bone The total amount of generated heat is directly proportional to the mass of monomer used (Trommsdorf 1963)
In more detail the polymerization process of acrylic cement can be described as follows (Charnley 1970 de Wijn 1974 Oest *et al* 1975 Debrunner *et al* 1976) to the liquid com ponent are added an inhibitor or stabilizer (hydroquinon) that prevents the monomer from polymerizing spontaneously and also an initiator (benzoyl peroxide) To the power compo - nent an accelerator is added (dimethyl paratoluidine DPT) After mixture of the components the initiator is decomposed by the accelerator into so called radicals molecule that trigger off the polymerization of the monomer The compositions of the various commercial brands vary to some extent The characteristics of the polymerization process are usually defined with reference to the temperature time curve (fig 1 3) the time from starting the mixture

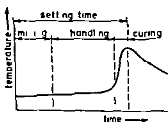


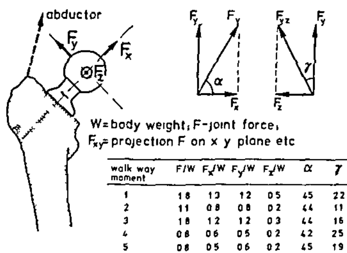
fig 1 3 A typical temperature time curve of curing acrylic cement Terminology for phases in the polymerization process is shown (see also text)

until the peak temperature occurs is called the setting time which is roughly 10 minutes the first stage of this period that takes about 3 to 4 minutes and in which the mixture tends to stick to the surgical glove is called the mixing time or dough time the second stage that takes about 4 5 minutes and in which the mixture is still dough but no longer sticks to the glove is called the handling time There appears to be no complete agreement on this terminology in the literature and moreover these stages are not uniquely defined because the temperature time curve depends not only on the cement properties but also on the heat conduction properties of the adjoining materials hence on the specific circumstances
The mixture reaches its ultimate hardness (sets) somewhat prior to the occurrence of the peak temperature Hardness tests during the polymerization process were carried out by Debrunner *et al* (1976) an example of results is shown in fig 1 4

during normal walking can be as high as 4 5 to 5 5 times body weight Forces in the knee joint would reach about 3 times body weight and in the hip joint about 4 times body weight during normal walking, according to Paul (1974) During stairs walking or sport activities these values will be even higher

The loading on the artificial joint is not necessarily equal to the loading on the natural joint Even if the same level of activity were assumed, differences may be due to the positioning of the joint relative to the bone, the constraints offered by the prosthesis in comparison to those of the natural joint, and the incidence of friction

Valuable data on hip joint loading was supplied by Rydell (1966) who implanted endo prostheses instrumented with strain gauges in two patients and measured the hip joint forces in several activities An example of his results is shown in fig 1 1 Magnitude and direction



walk way moment	F/W	F_x/W	F_y/W	F_z/W	α	γ
1	1 8	1 3	1 2	0 5	45	22
2	1 1	0 8	0 8	0 2	44	11
3	1 8	1 2	1 2	0 3	44	16
4	0 8	0 6	0 5	0 2	42	25
5	0 8	0 5	0 6	0 2	45	19

fig 1 1 Magnitudes, directions and points of application of hip joint forces as measured b. Rydell (1966), using an instrumented hip prosthesis implanted in a 51 yr old male patient (right leg, weight 75 kg), during level walking at 1 3 m/sec Averages out of 12 measurements Also shown is the resultant force of the important abductor muscle group on which magnitude and direction the joint force partly depends

of the resultant joint forces varied considerably during the different activities and in the two patients The maximal average force amounted to roughly 4 3 times body weight ($\alpha \approx 32°$ and $\gamma \approx 15°$) during running at 2 5 m/sec and was measured in patient no 2 (56 yrs female, 45 kg)

The loading that is transferred by the fixation system ultimately determines the stress distri bution This loading, in addition to the joint loading, depends on the geometry of the implant In the case of the hip joint, the neck length and the varus valgus angle of the neck are important parameters Other forces, too, will influence the stress distribution in the bone prosthesis structure as for instance the abductor muscle forces (fig 1 1)

1 5 Acrylic cement

Acrylic cement is a two component material The solid powder component consists princi pally of polymethylmethacrylate (PMMA) or polymer, the liquid component principally of monomethylmethacrylate (MMA) or monomer Shortly after mixture of the two component

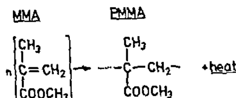


fig 1 2 Description of the polymerization reaction in which monomethylmethacrylate molecules are connected to form polymer chains

the polymerization process of the monomer starts (fig 1 2) ultimately embedding the PMMA powder into a PMMA matrix so that a solid substance remains During the polymerization process heat is generated which has to be conducted through the adjoining materials *implant and bone* The total amount of generated heat is directly proportional to the mass of monomer used (Trommsdorf 1963)
In more detail the polymerization process of acrylic cement can be described as follows (Charnley 1970 de Wijn 1974 Oest *et al*, 1975 Debrunner *et al* 1976) to the liquid component are added an inhibitor or stabilizer (hydroquinon) that prevents the monomer from polymerizing spontaneously and also an initiator (benzoyl peroxide) To the power component an accelerator is added (dimethyl paratoluidine DPT) After mixture of the components the initiator is decomposed by the accelerator into so called radicals molecule that trigger off the polymerization of the monomer The compositions of the various commercial brands vary to some extent The characteristics of the polymerization process are usually defined with reference to the temperature time curve (fig 1 3) the time from starting the mixture

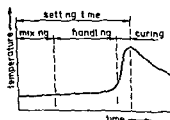


fig 1 3 A typical temperature time curve of curing acrylic cement Terminology for phases in the polymerization process is shown (see also text)

until the peak temperature occurs is called the setting time which is roughly 10 minutes the first stage of this period that takes about 3 to 4 minutes and in which the mixture tends to stick to the surgical glove is called the mixing time or dough time the second stage that takes about 4 5 minutes and in which the *mixture* is still dough but no longer sticks to the glove is called the handling time There appears to be no complete agreement on this terminology in the literature and *moreover* these stages are not uniquely defined because the temperature time curve depends not only on the cement properties but also on the heat conduction properties of the adjoining materials hence on the specific circumstances
The mixture reaches its ultimate hardness (sets) somewhat prior to the occurrence of the peak temperature Hardness tests during the polymerization process were carried out by Debrunner *et al* (1976) an example of results is shown in fig 1 4

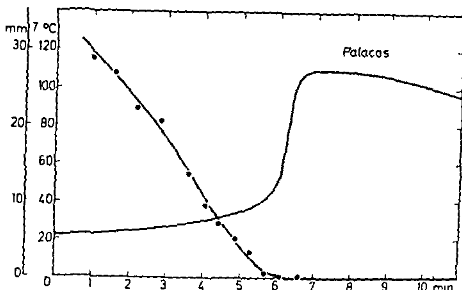


fig 1 4 Temperature and hardness of curing acrylic cement, as function of time Hardness was measured as penetration depth (mm) at constant force (reproduced with permission of Debrunner et al, 1976)

During the polymerization process the mixture undergoes dimensional changes due to volume contraction of the polymerizing component (density of PMMA 1 18 kg/m^3, density of MMA 0 94 kg/m^3), expansion of enclosed air and vaporized monomer bubbles and thermal shrinkage The first two mechanisms are active during the setting phase while the last named occurs during the cooling phase An overall expansion of 2 to 5 volume percent has been mentioned in the literature (de Wijn *et al*, 1975) These authors concluded that in fixating intramedullary stems the initial expansion will propably cause the mixture to flow in a longitudinal direction while the cooling will cause the layer to shrink around the stem, leaving a gap between the bone and the cement mass (at the so called cement bone interface) and locked in stresses in the cement layer Sometimes these stresses will cause the cement mantle to fracture during the operation (Miller *et al*, 1976, Chao 1979)
The steep rise in temperature after the mixture has set is related to an acceleration of the polymerization process called the Trommsdorf' or gel effect
The initial velocity of the polymerization process depends very much on the initial temperature owing to the temperature sensitivity of the catalyser The polymerization is never complete It has been shown that there is 2 to 5% residual monomer in the cement and that 1 to 2% gradually enters into the tissue (e g Kutzner *et al* 1974) This residual monomer may cause damage to the bone tissue adjoining the cement (e g Mohr 1958)
Apart from the ones already mentioned, other components may have been added to the cement like antibiotics or radiopaque fillers (barium sulfate, $BaSO_4$ or zirconium oxide, ZrO_2)

The mechanical properties of acrylic cement (e g strength and stiffness) as present in the patient are different from those of industrial PMMA Differences are due to inhomogeneties caused by air entrainment and inclusion of blood and tissue debris during the mixing process antibiotic and radiopaque additives and inhomogeneties caused by vaporized monomer during the polymerization process The properties also change in the course of time due to temperature influences, moisture uptake and ageing Extensive studies on mechanical properties of bone cement preoperative as well as postoperative have been published by Muller (1975

Conditions	Young s modulus (N/mm^2)	Ultimate tensile strength (N/mm^2)	Elongation at fracture (%)
industrial PMMA	$2\ 8 \times 10^3$	74	8 4
acrylic cement laboratory conditions	$2\ 6 \times 10^3$	43	2 0
10 months in the body simulated tested at 37°C	$1\ 9 \times 10^3$	23	1 7

table 1 I Approximative average value of five commercial brands for mechanical properties of acrylic cement tested under different conditions compared to properties of industrial PMMA (after Kusy 1978)

1979) Lee *et al* (1978) and Kusy (1978) Kusy reports mechanical properties for five brands tested under different conditions (table 1 I) The acrylic cement is many times stronger in compression than in tension Lautenschlager *et al* (1974) report 20 7 to 34 5 N/mm^2 ultimate compressive strength and 6 9 to 20 7 N/mm^2 ultimate tensile strength It should be remarked that bone cement is somewhat viscoelastic hence differences in strain rate may apart from other circumstances explain the variety in results to some extent Lee *et al* (1978) investigated influences of several variables that may weaken the bone cement a summary of their results is shown in table 1 II

Variable	Possible % change in strength		
	UCS		UTS
Environmental temp 37°C		- 10%	
Equilibrium moisture content		- 3%	
Ageing		- 10%	
Radiopaque fillers		- 5%	
Antibiotics		- 4%	
Inferior mixing technique		- 21%	
Insertion technique delay	- 40%		- 54%
— pressure		+ 20%	
Inclusion of blood and tissue debris	- 16%		- 70%

table 1 II Possible changes in compressive (UCS) and tensile (UTS) ultimate strength by different variables separately (after Lee et al 1978)

Presently many research efforts are devoted to the development of alternative intermediate materials that have the same favorable properties as PMMA but lack the adverse side effects and give better fixation possibilities Many of these efforts are concerned with porous

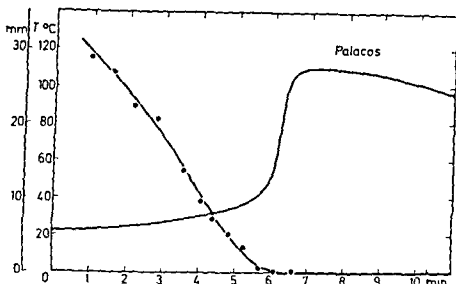


fig 1 4 Temperature and hardness of curing acrylic cement, as function of time Hardness was measured as penetration depth (mm) at constant force (reproduced with per mission of Debrunner et al, 1976)

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Fig 1 6 shows an example of this phenomenon

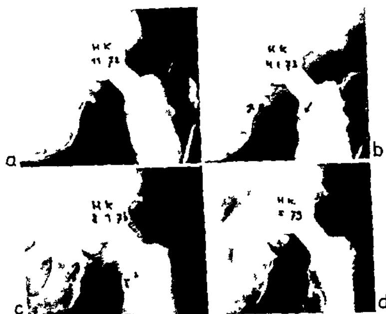


fig 1 6 Roentgen series showing calcar and acetabular (medial side of the cup) bone resorption (indicated by arrows) after total hip replacement respectively directly (a) 2 months (b) 3 years (c) and 6 5 years (d) postoperative (patient material Department of Orthopedics University of Nijmegen the Netherlands)

Many investigations (cited in section III) have shown that the orientation and density distribution of trabecular and cortical bone coincide with optimal structural requirements to resist the stresses due to the loading of the bone From these observations Wolff s law has been formulated (Koch 1917) stating that bone growth is related to the stress (or strain[1]) pattern in the bone It would according to this law not be illogical if at least part of the remodeling phenomena were caused by the effect of the greatly changed stress pattern in the bone after the joint has been replaced Especially disuse osteoporosis as the name indicates is attributed to this stress effect

The process of calcar resorption is not yet fully understood Its occurrence has been attributed to effects of vascular damage (e g Rhinelander 1972 1979) while some investigators support the opinion that it is initiated by foreign body reactions to wear particles (e g Willert *et al* 1976 1978)
Another hypothesis often put forward is that of a stress related effect Especially in the calcar region the stress pattern is greatly changed after joint replacement Upon joint loading unphysiological radial and shear stress components will be present at the inner surface of the bone (fig 1 7) and an unphysiological circumferential stress component will be present in the bone cortex The axial normal stress in the cortex will be higher than in the natural case if a collar is applied on the prosthesis but will be practically absent if no collar is used (fig 1 7) Hence resorption might occur due to overloading but also to underloading

materials, allowing bone to grow in, as for instance porous acrylic cements (Feith, 1975, de Wijn *et al*, 1977, 1978, Ypma *et al*, 1978) and porous implant coatings (e g Ducheyne *et al*, 1977, Spector *et al*, 1978)

1 6 Bone reaction to joint replacement

Bone tissue can be divided into sponge like trabecular bone and dense cortical bone Trabecular or spongeous bone is for instance found in the proximal and distal parts of the long bones, near the joints (fig 1 5 a) Hence the greater part of the bone to be resected for joint replacement will be spongeous bone (fig 1 5 b)

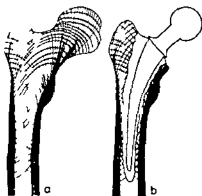


fig 1 5 A schematic representation of bone structure, showing trabecular bone and cortical bone in the upper femur, before (a) and after (b) hip joint replacement (reproduced with permission of Willert and Semlitsch, 1976)

Bone is a living material and is constantly being resorbed and appositioned a process called bone remodeling Due to this process the conditions in the biological part of the bone prosthesis system gradually alter to a greater or lesser extent after the operation Initially the bone remodeling process is usually restorative with respect to the surgical trauma At a later stage progressive resorption caused by biochemical or mechanical factors may seriously endanger the service life span of the system

A bone reaction that is of great importance for the functioning of the bone prosthesis system is that of the bony implant bed, during and directly after the operation but also at a later stage The behavior of this bone cement interface will be discussed in paragraph 1 7 After intramedullary joint fixation, reactions occur that are typical for all intramedullary procedures An extensive literature review with respect to these reactions is given by Feith (1975) The reactions, that are usually attributed to a disturbance of the intramedullar vascularity that nourishes the cortex, include necrosis of the inner part of the cortex the appearance of large resorption lacunae in the middle third of the cortex (spongiozation of the cortex, Slooff, 1970) and subperiosteal bone apposition
Another reaction often encountered is a phenomenon called disuse osteoporosis , a process that may gradually occur postoperatively and in which the cortical bone becomes porous thus affecting its mechanical properties such as strength and stiffness A last significant reaction specific to hip joint replacement is called calcar resorption a process in which the bone rim in the calcar region resorbs to a greater or lesser extent (e g Charnley 1978)

adequate performance of the bone prosthesis system However due to the biological character of the bone the structure of the interface will change postoperatively both immediately and in the course of time Histological studies on the short and long term reaction of the bony implant bed were for example published by Charnley (1970 1978) Willert *et al* (1972 1974 1976 1978) and Vernon Roberts and Freeman (1976 1977)
In the first instance directly postoperatively a layer of necrotic bone of a few mm thickness is usually found at the interface Three factors may contribute to this phenomenon
- the reaming of the implant bed and the disturbed vascularity
- the thermal effects of the heat of polymerizing of the acrylic cement
- the cytotoxic effect of the residual monomer

Vernon Roberts and Freeman (1976 1977) believe that the first effect is the principal cause because they found necrotic zones of bone in regions where neither heat nor monomer could have penetrated According to Willert and Frech (1976) the amounts of residual monomer released into the bone tissue will certainly be capable of causing tissue necrosis Several experimental temperature measurements in bone adjacent to polymerizing cement (as cited in section II) have not resulted in a conclusive opinion with respect to the thermal effect owing to the wide spread of results
A histological study concerning adverse side effects of bone cement in rabbits was published by Feith (1975) He concluded that reaming and residual monomer especially an overdose both cause bone necrosis at the interface but that the principal causative factor is the heat of polymerizing. These experiments will be further discussed in section II

Later postoperatively the layer of necrotic bone is resorbed and replaced by soft tissue in which new bone is formed The structure of this new bone layer is not necessarily identical to that of the original layer Vernon Roberts and Freeman (1976) report that the initial trabecular shaped interface ensuring good mechanical interlocking between cement and bone is often lost and replaced by a more or less smooth bone layer
Also the new bone is not in direct contact with the cement because a fibrous tissue layer always remains This layer may be extremely thin and caused by a normal tissue reaction to the foreign body (Charnley 1970 1978) Often however this layer is reported as quite thick and to appear on radiographs as a radioluscent demarcation line Willert and Puls (1972) measured the layer to be usually 0 1 to 1 5 mm thick Most authors believe that the occurrence of this thick layer is related to micromovements and stresses at the interface (e g Charnley 1970 Willert and Puls 1972 Willert *et al* 1974 Vernon Roberts and Freeman 1977)
If a fibrous layer (radioluscent line) is abnormally thick or its thickness increases progressively it is usually regarded as a sign of forthcoming prosthesis loosening (see chapter 2)
The strength of the cement bone interface depends on the amount of mechanical interlocking Studies of the initial tensile and shear strengths of cement cancellous bone interfaces using push out tests on cadaveric material were carried out by Kolbel *et al* (1976) They report an average tensile strength of $1\,9 \pm 0\,9$ N/mm^2 and an average shear strength of $3\,4 \pm 0\,6$ N/mm^2 Halawa *et al* (1978) carried out comparable shear strength tests under different circumstances they found an average increase of 100% in strength when a 2 3 mm cancellous bone layer was retained instead of a 5 mm layer an average increase of 200% when the bone surface was cleaned before cementing an average increase of 60% when the cement was inserted 3 min instead of 6 min after the beginning of mixing and an average increase of 100% when pressure (0 15 N/mm^2) was put to the curing cement
These properties will no doubt be seriously affected by interface remodeling and the formation of fibrous tissue layers as discussed previously

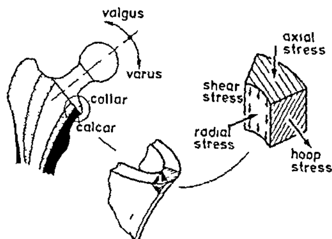


fig 1 7 An example of a hip endoprosthesis with a collar, to rest on the calcar bone rim Varus valgus position as well as stress components in the calcar region are indicated the axial stress component is a physiological one, the radial and shear stresses at the cement bone interface and the circumferential (hoop)stresses in the bone, inflicted by the prosthesis, are quite unnatural

Bocco *et al* (1977) and Griss *et al* (1978) found a significant reduction in the incidence of calcar resorption when the (collarless) prosthesis was placed in valgus position (fig 1 7), compared to a fixation in varus position thus changing the loading system relative to the fixation and also increasing the cement layer thickness on the medial side Although most experimental and theoretical studies as will be reviewed in section III support the advantages of a collar, there appears to be no clinical evidence as to its benefit (e g Charnley 1977 1978, Lee *et al*, 1977, Muller and Niederer 1977) Significant data was published by Diehl (1975) and by Griss *et al* (1978) indicating that due to usually minor bone resportion at the collar calcar contact region and the formation of a soft intermediate tissue layer the collar will not be effective anyway

1 7 The cement bone interface

The cement bone interface is the key region for success or failure of the artificial joint replacement many complications find their origin at this junction of biological and technical material Its initial shape depends on the bone structure more or less smooth if cortical bone forms the implant bed and rather wild if the implant bed consists of trabecular bone There is no chemical bond between the acrylic cement and the bone Mechanical interlocking between the cement and the trabecular bone is possible to an extent depending on a number of factors the viscosity of the cement mixture when inserted the pressure applied to the cement mass, the cleanliness of the implant bed and dimensional changes of the cement
As already mentioned in paragraph 1 1 it has recently been advocated to insert the mixture early during a more liquid phase and to press the cement into the trabecular spaces using specially designed equipment and an intramedullary plug in the case of stem fixation (Markolf and Amstutz 1976 Oh *et al* 1978 Krause *et al*, 1979 Weber and Stuhmer 1979) It has also been advised to clean the implant bed after reaming using pulsating pressurized water flow (Narten *et al*, 1977 Halawa *et al* 1978, Miller *et al*, 1978)
An optimal mechanical interlocking between cement and bone will be advantageous for an

Stuhmer (1976) reports a loosening incidence of 4 3% in 2577 patients who received a total hip replacement only 10 6% of the material could be qualified as late results (more than 5 yrs follow up) 87 5% of the loosened cases occurred after 450 days postoperatively The loosening incidences reported in comparable follow up studies usually range between 0% and 7% with occasionally a higher number (e g Amstutz *et al*, 1970 1978, Bergstroem *et al*, 1973 Charnley and Cupic 1973 Lazanksy 1973 Weber and Charnley, 1975, Eftekar *et al*, 1976 Slooff *et al*, 1976 Stuhmer, 1976 Witt and Hackenbroch, 1976 Rütt 1977, Visuri *et al*, 1977)
Aseptic loosening occurs in all the various types of prostheses Because of the large number of parameters involved (design used materials used surgical procedures individual properties and level of activity of the patients) statistical analyses usually do not result in significant relations between the parameters and the incidence of loosening.
In many series aseptic loosening is the complication most occurring but although undesirable an incidence of 7% cannot be called alarming However in most patient reviews the number of postoperative years were relatively rather short and it is being shown in an increasing number of publications that the number of artificial hip-joints that loosen aseptically rises sharply with the number of postoperative years as opposed to septic loosening (due to infection) This was illustrated by an investigation of Witt and Hackenbroch (1976) who calculated average loosening incidences from publications concerning reviews on hip replacements carried out between 1963 and 1973 (*table 2 1*)

Postoperative period (years)	Average incidence of aseptic loosening	Average incidence of septic loosening
0 7 1 3	1 6%	2 4%
1 7 4 5	4 %	2 3%
5 9 5	8 %	3 3%

table 2 1 Average loosening percentages septic as well as aseptic, calculated from various hip replacement reviews (after Witt and Hackenbroch, 1976)

Due to the progressively occurring incidence aseptic loosening is considered as a very severe complication and many authors thus maintain that joint replacements should remain restricted to older patients (60 yrs and over) (e g Muller 1974 Stuhmer 1976)
Disturbing reports have been published recently on radiological reviews of patients who received a total hip replacement Beckenbaugh and Ilstrup (1978) reviewed 333 Charnley hip arthroplasties after 4 to 7 postoperative years They looked for roentgenographic evidence of loosening of the femoral component which they defined as significant subsidence of the prosthesis with respect to the bone They found this evidence in 24% of the cases Of the loosened cases 20% showed definite roentgenographic evidence of associated fracture in the cement The overall clinical results of the loosened group was poor although only 8% had required re-operation as yet The authors ascribe the loosening principally to cement fracture which will be progressive in their opinion and ultimately require revision of all loosened hips
A comparable investigation was reported by Gruen and Amstutz (1977) 398 total hip replacements after 0 5 to 6 postoperative years were reviewed radiographically Radiographic evidence of loosening which they defined as cement cracks and wide radioluscent lines at the cement bone interface was found in 19 5% of the cases In 16 7% these signs

CHAPTER TWO

COMPLICATION OF ARTIFICIAL JOINT REPLACEMENT

2 1 Introduction

Results and complications of artificial joint replacement are usually studied in patient reviews The results of these reviews, or follow up studies, are becoming available in ever increasing numbers In the first studies published the number of postoperative follow up years was usually rather small, recently studies on large series of late results (more than 5 yrs postoperatively) have been reported, especially on hip replacement

The complications of artificial joint replacement are usually divided into three categories (Muller, 1976, Schulitz and Dustmann, 1976) (1) pre-operative complications (mentioned in chapter 1 1), (2) early complication (up to four weeks postoperative, including dislocation of the joint, haematoma, thrombosis, allergic reactions, early infection and a few others) and (3) late complications (including infection aseptic loosening, mechanical failure of the implant components, bone fracture, ectopic bone formation, migration of the implant and a number of others) An extensive follow up study on 2256 patients who received total hip replacement was reported by Gschwend (1976) Postoperative complications were found in 10 68% of the cases, of which bone perforation (femur and acetabulum) accounted for approximately 8% and no other specific complication occurred in more than 1% of the cases Early complications were found in 29 42% of the cases, of which 15 32% were local, the largest group consisted of haematoma (8%) and infection (1 5%)
All these complications do not in general cause failure of the joint replacement, as opposed to deep infection, aseptic loosening (loosening without infection) and mechanical failure of the implant For deep infection, usually leading to re operation incidences of 0 to 11% are reported in the literature (e g Green 1976 Hunter and Dandy, 1977)
Aseptic loosening and implant failure are subjects of the present investigation and will be treated in somewhat more detail

2 2 Aseptic loosening

Aseptic loosening occurs when the implant loosens with respect to the bone by a cause other than infection Usually patients feel pain on load bearing and the loosening can be established by clinical and radiological examination and by using scintigraphy (Feith *et al* 1976), although not always with certainty As a phenomenon it can either be fracture of the cement or a loosening of the cement bone interface, leading to movement between the two materials Sometimes prosthesis fracture is also accounted as loosening Although a fractured component will usually be 'loose' and loosening of the implant may on the other hand induce implant fracture, this complication is treated separately here
Loosening of the implant most often results in a revision operation The cause of the loosening is not always apparent although its incidence is often found together with roentgenographically established cracks in the cement mantle, inadequate cementing (incom plete mantle), thick radioluscent lines inadequate positioning calcar resorption or a combi nation of these phenomena During the re operation fractioned cement or a thick layer of fibrous tissue are sometimes found

Although this is being contradicted by Charnley (1978) many investigators expect that the roentgenographic evidence indicates a forthcoming need for revision

Considerably less literature is available on other than hip joint replacements For the knee joint loosening incidences have been reported of 4% to 30% the higher numbers being representative of the hinged prostheses (Peterson 1977, Freeman *et al* 1978 Ducheyne *et al* 1978 Lacey 1978) Loosening incidences of 3% to 30% were reported for elbow prostheses the high percentages certainly caused by the high torsional loading of the humeral component (Schlein 1976 Nederpelt 1978)

2 3 Implant failure and bone fracture

Mechanical failure of the artificial joint itself can either be due to fracture or plastic defor mation of a component, while excessive wear may also be reckoned among the causes Fracture of a component is frequently reported as occurring in femoral stems of hip prostheses Martens *et al* (1974) reported six femoral stem fractures out of a series of 56 Charnley Muller total hip replacements (10 7%) All fractures were located in the middle third of the stem and could be ascribed to fatigue At least part of the fractures were preceded by fractures in the cement
Ducheyne *et al* (1975) reported two stem fractures in a series of 90 Charnley total hip replacements Both fractures occurred in the proximal part of the stem (at the curvature) and were preceded by plastic deformation Galante *et al* (1975) reviewed 21 articles concerning follow up studies of a total of 6 110 hip replacements and found that re opera tion due to fractured stems was needed in only 0 15% of the cases Charnley (1975) investigated 17 cases of fractured stems out of a series of approximately 6 500 total hip replacements (0 26%) He found that the incidence of stem fracture among patients over 76 kg in weight was 2 6% and for patients over 89 kg in weight even 6 1% Besides weight he considers erosion or calcar resorption as the possible predominant factor in stem failure Collis (1977) reported 4 stem fractures out of 200 total hip replacements (2%) all in patients who weighed over 91 kg. The postoperative follow up period was 4 to 6 years All stem failures were preceded by cement fractures in the proximal medial region Rostoker *et al* (1978) investigated 34 fractured stems All fractures were found to be due to fatigue failure In all the fractured cases the patient exhibited at least one of the risk factors which they define as high body weight malpositioning lack of calcar support and roentgenographic signs of loosening They also found metallurgical deferts in 31 of the fractured stems It should be remarked here that on detailed investigation no material will be found absolutely pure
Dobbs (1977) investigated 29 cases of fractured stems and on the basis of this review developed a statistical model to predict the incidence of failure Owing to uncertain para meter values his model predictions are probably not very accurate but when more accurate data become available on the relation betwe n jo ct loading and maximal stem stresses taking the risk factors into account such models could conveniently be used in post operative radiographic patient evaluation

Fractures of acetabular components of total hip prostheses are not often reported in the literature Fractures of elbow and knee prostheses stems have been reported occasionally while finger joint stems appea to f acture more frequently (Walker 1977) Plastic defor mation (cold creep) may occur in the plastic tibial components of artificial knee joints (Walker 1977 Lacy 1978 Ducheyne *et al*, 1978)

increased progressively A radiographic analysis of 100 Charnley total hip replacements with a follow up of 5 to 7 years was carried out by Salvati *et al* (1976) They established clear radioluscent lines at the cement bone interface of the femoral component in 55% of the hips, 25% remained constant, 10% decreased and 21% gradually increased in thickness They established radioluscent lines in the acetabular component in 93% of the hips, the line remained stable in 41%, decreased in 23% and gradually increased in 29% of the cases Cement cracks they could only identify in 3% of the cases

Loosening of acetabular components of artificial hip joints is reported about as frequently as of femoral components, in some series its incidence is even higher (e g Dietschi *et al*, 1976)
A loosening incidence of approximately 20% of acetabular cups was reported by Visuri and Laurent (1977) in a series of 351 Charnley total hip replacements with 5 to 7 years follow up, of the remaining 80%, 29% showed roentgenographic signs of loosening this being a radioluscent zone of 1 to 12 mm at the cement bone interface
In a series of 95 total hip replacements after 4 to 7 postoperative years, Maier *et al* (1977) report 14 7% roentgenographically and clinically established cases of acetabular cup loosenings, in addition they found 4 9% of only roentgenographically established loosenings

Much better results have been reported by Charnley (1978) In a series of 396 patients who received total hip replacement, with 12 to 15 years follow up, 0 25% had to be re-operated due to loose femoral components and 1 26% due to loose acetabular components For his total material of 10,000 total hip replacements he reports a revision percentage of 0 25% due to loose femoral or acetabular components A summary of some roentgenographical data concerning this series as established in several investigations cited by Charnley (1978), is shown in table 2 II

Study No	1	2	3	4	5	6	7	8	9
hip replacements	138	106	6,649	141	190	169	216	547	115
postoperative years	7 8	9 10	3 14	8 11	3 8	8 11	1 6 2 6	8	12 15
Femoral component									
subsidence	–	–	1 5%	–	–	–	12 6%	8 9%	8%
cement fracture	–	–	1 5%	–	–	–	23 3%	8 6%	–
calcar resorption	–	99 9%	–	–	37 2%	70%	23 1%	–	95%
Acetabular component									
migration	1 4%	1 4%	–	9 2%	–	–	–	–	11%
no radioluscent line	–	–	–	31 3%		–	–	–	41%
moderate radioluscent line	–	–	–	60 3%	–	–	–	53 7%	34%

table 2 II Some results of radiographic reviews of total hip replacements (after Charnley, 1978)

In summarizing it is found that the number of failed hip replacements increases late post operatively due to aseptic loosening Many patients although still asymptomatic, show roentgenographic evidences of loosening such as cement fractures subsidence of the prosthesis and progressive radioluscent demarcation lines at the cement bone interface

Although this is being contradicted by Charnley (1978) many investigators expect that the roentgenographic evidence indicates a forthcoming need for revision

Considerably less literature is available on other than hip joint replacements For the knee joint loosening incidences have been reported of 4% to 30% the higher numbers being representative of the hinged prostheses (Peterson 1977 Freeman *et al* 1978 Ducheyne *et al*, 1978 Lacey, 1978) Loosening incidences of 3% to 30% were reported for elbow prostheses the high percentages certainly caused by the high torsional loading of the humeral component (Schlein, 1976 Nederpelt 1978)

2 3 Implant failure and bone fracture

Mechanical failure of the artificial joint itself can either be due to fracture or plastic defor mation of a component while excessive wear may also be reckoned among the causes Fracture of a component is frequently reported as occurring in femoral stems of hip prostheses Martens *et al* (1974) reported six femoral stem fractures out of a series of 56 Charnley Muller total hip replacements (10 7%) All fractures were located in the middle third of the stem and could be ascribed to fatigue At least part of the fractures were preceded by fractures in the cement
Ducheyne *et al* (1975) reported two stem fractures in a series of 90 Charnley total hip replacements Both fractures occurred in the proximal part of the stem (at the curvature) and were preceded by plastic deformation Galante *et al* (1975) reviewed 21 articles concerning follow up studies of a total of 6 110 hip replacements and found that re-opera tion due to fractured stems was needed in only 0 15% of the cases Charnley (1975) investigated 17 cases of fractured stems out of a series of approximately 6,500 total hip replacements (0 26%) He found that the incidence of stem fracture among patients over 76 kg in weight was 2 6% and for patients over 89 kg in weight even 6 1% Besides weight he considers erosion or calcar resorption as the possible predominant factor in stem failure Collis (1977) reported 4 stem fractures out of 200 total hip replacements (2%) all in patients who weighed over 91 kg The postoperative follow up period was 4 to 6 years All stem failures were preceded by cement fractures in the proximal medial region Rostoker *et al* (1978) investigated 34 fractured stems All fractures were found to be due to fatigue failure In all the fractured cases the patient exhibited at least one of the risk factors which they define as high body weight malpositioning lack of calcar support and roentgenographic signs of loosening They also found metallurgical defects in 31 of the fractured stems It should be remarked here that on detailed investigation no material will be found absolutely pure
Dobbs (1977) investigated 29 cases of fractured stems and on the basis of this review developed a statistical model to predict the incidence of failure Owing to uncertain para meter values his model predictions are probably not very accurate but when more accurate data become available on the relation between joint loading and maximal stem stresses, taking the risk factors into account such models could conveniently be used in post operative radiographic patient evaluation

Fractures of acetabular components of total hip prostheses are no [illegible] literature Fractures of elbow and knee prostheses stems have be[illegible] while finger joint stems appear to fracture more freque[illegible] mation (cold creep) may occur in the plastic tibial co[illegible] (Walker 1977 Lacy 1978 Ducheyne *et al* [illegible]

increased progressively A radiographic analysis of 100 Charnley total hip replacements with a follow up of 5 to 7 years was carried out by Salvati *et al* (1976) They established clear radioluscent lines at the cement bone interface of the femoral component in 55% of the hips, 25% remained constant, 10% decreased and 21% gradually increased in thickness They established radioluscent lines in the acetabular component in 93% of the hips, the line remained stable in 41%, decreased in 23% and gradually increased in 29% of the cases Cement cracks they could only identify in 3% of the cases

Loosening of acetabular components of artificial hip joints is reported about as frequently as of femoral components, in some series its incidence is even higher (e g Dietschi *et al*, 1976)
A loosening incidence of approximately 20% of acetabular cups was reported by Visuri and Laurent (1977) in a series of 351 Charnley total hip replacements with 5 to 7 years follow up, of the remaining 80%, 29% showed roentgenographic signs of loosening this being a radioluscent zone of 1 to 12 mm at the cement bone interface
In a series of 95 total hip replacements after 4 to 7 postoperative years, Maier *et al* (1977) report 14 7% roentgenographically and clinically established cases of acetabular cup loosenings, in addition they found 4 9% of only roentgenographically established loosenings

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CHAPTER THREE

OBJECTS AND METHODS OF THE PRESENT STUDIES

3 1 Introduction

Clinical and roentgenographic follow up studies as discussed in the previous chapter give valuable information on the adequacy of the treatment in general the kinds and numbers of problems that may be encountered and the way in which complications manifest themselves Usually no definite relation can be found between a complication and its cause and when it is found it is mostly statistical and not causative due to the many uncertain parameters in volved in a joint replacement Especially with respect to such a treatment however a funda mental understanding of the relations between causes and effects of complications is of great importance It has been mentioned previously that an artificial joint has to perform without complications for the full postoperative life span This means that ten to fifteen years would have to pass before the data on the general adequacy of a specific design or procedure would be complete This is not a good basis for trial and error procedures and hence in our opinion all available means to predict the performance of a prosthetic device should be applied However complicated the (biological) bone prosthesis structure is it is certainly possible to acquire fundamental knowledge on certain aspects If for example a fundamental concept on the relation between the structural parameters and the purely mechanical performance of the prosthesis in the body can be developed this might not lead to an immediate answer to the question of the optimal design features since also other com plicated aspects are involved but it would at least provide a firm basis or no basis for a part of the arguments commonly used in solving this problem and it would at least extend the available means for a long term performance prediction

In orthopedic research studies of animal or laboratory models are often applied Another method that is not very common is the use of theoretical or mathematical models For certain research objects with respect to some problems of artificial joint replacement too the use of these methods have many advantages (Huiskes and v Heugten 1974) In these m thods the properties of the system to be investigated are described mathematically and by using theories are interrelated in formulas that describe the system behavior One of the advantages of such theoretical analyses is the possibility to investigate influences of parameter changes and in this way acquiring a fundamental comprehension of relations between pa amete s and effects In the following sections II and III theoretical methods will be used in an effort to contribute to a more fundamental understanding of some aspects of artificial joint replacement These studies concern a stress analysis of intramedullary fixated prostheses principally focussed on the hip join and a heat conduction analysis of acrylic cement in situ Although the use of theoretical methods will certainly not be the ultimate answer to problems of artificial joint replacement it will hopefully be shown that these (engineering) methods deserve their rightful place next to follow up studies animal experiments and laboratory experiments in orthopedic research and that especially when used in interactive combination with these experiments an additional dimension in research possibilities evolves

Occasionally plastic deformed metal intramedullary stems are also encountered Recently a case of thermal deformation of a polyethylene tibial component of an artificial knee joint has been reported (Volz and Gradillas, 1978) The authors believe that such a deformation, caused by the polymerization heat of the acrylic cement, occurs more often and they found some evidence of it in several roentgenograms

There is no doubt that prostheses components are subject to wear in the body, which does not necessarily have to present a problem However, if the wear is excessive to an extent that it can no longer perform its function, it will result in failure Much research has been and is being done on wear of various biomaterials (e g Charnley and Halley, 1975, Walker, 1977 Swansson and Freeman, 1977)
The wear rates of the materials presently used are such that the wear in itself appears to present no serious problems This might be different, however, if younger patients received joint replacements

Fracture of the bone, postoperatively, is not a complication often encountered after artificial joint replacement In a series of 5400 total hip arthroplasties McElfresh and Coventry (1974) reported 10 postoperative bone fractures, 6 of which were in the femur 3 in the acetabulum and one in both The acetabular fractures were not related to the hip replacement In some of the femoral fractures defects of the cortex due to screw holes or misdirected reaming were apparent
Scott *et al* (1975) also reported occasionally occurring femoral fractures always related to cortical defects near the prosthesis stem tip

A bone failure mode with a higher incidence, already mentioned in chapter 2 2, is the gradual sinking of a component through the bone Especially protrusion or migration of the artificial head or the cup of the hip joint through the acetabulum (e g Hoogbergen *et al*, 1975, Charnley 1978) and sinkage of the tibial knee component in the tibia (e g Walker, 1977 Freeman *et al* 1978) occur sometimes The protrusion may be caused by interface bone remodeling, stress (fatigue) fractures of the subchrondal spongeous bone or a combination of both

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3 2 Heat conduction analyses

As was discussed in paragraph 1 7, thermal damage due to the polymerization heat of acrylic cement is regarded as a possible factor contributing to necrosis of the bony implant bed It was the object of the analysis presented in section II to establish whether the temperature values in the bone, during implant fixation, may be such as can cause thermal damage and, if so, what measures can be taken to reduce the chances of thermal damage

Between cause (heat of polymerizing) and effect (bone temperature) there is a relation that depends on many parameters The heat of polymerizing itself depends on the amount of monomer in the mixture and hence on its composition
If the cement mass were completely isolated from its neighborhood, the temperature rise (ΔT) could easily be calculated from $Q = C\Delta T$, where Q denotes the total amount of polymerization heat and C the heat capacity As the cement mass is in contact with its adjoining materials, implant and bone, heat conduction occurs during and after the polymerization process Hence on one hand the rate of heat generation in the cement mass depends on the polymerization rate, while on the other the rate of heat transport depends on the heat conduction properties of the cement, the interface, the implant and the bone By applying approximative mathematical descriptions of these properties and using heat conduction theory, this process can be described in a mathematical (computer) model With this model the temperature as a function of time can be calculated at any point of the structure, given the parameters that describe the following properties
- the geometry of the implant the cement mass and the bone
- the heat capacities and the thermal conductivities of these materials
- the cement bone interface thermal conductivity
- the bone surface heat loss,
- the polymerization rate,
- the cement composition

In section II such a model will be used to predict the time and location dependent temperatures during fixation of artificial joints The calculated temperature values are compared with thermal damage threshold levels in order to estimate the chances of bone necrosis occurring By varying the system parameters, their influences on the temperature values are investigated from which quantitative guidelines for composition and application of the cement can be derived

3 3 Stress analyses

The stress analyses presented in section III are confined to intramedullary fixated prostheses and focussed especially on the hip joint although some results are valid for these systems in general
As was discussed in chapter 2, many complications of joint replacement are or may be related to stresses in the bone prosthesis structure Certainly stem cement and bone fractures are caused by locally exceeding the (fatigue) strength of the materials Although definite causes for interface bone remodeling development of fibrous tissue layers calcar bone resorption implant migration and disuses osteoporosis are as yet unknown there is some evidence that these phenomena are at least to some extent, stress related as well and thus it appears to be beneficial to provide a system in which the stress pattern is smooth and the stresses on and in bone are as natural as possible
For given joint forces the stress distribution in the stem in the bone, in the cement mantle

and at the interfaces depends on the geometry of the implant (for example stem length thickness taper etc) the geometry of the cement mantle (for example its thickness) and the geometry of the bone on the mechanical properties of the materials (for example their modulus of elasticity) and on the mechanical interface conditions By applying theories of continuum mechanics these properties can be described mathematically and interrelated in mathematical models With such models the stress values in the system can be approximated for given joint loading

It was the object of the analysis described in section III to contribute to better understanding of the relations between the geometrical and materials properties of the system components on one hand and the stresses in the system that result from a specific joint loading on the other To accomplish this simplified mathematical models of the intramedullary fixation structure were studied using various methods Also relatively simple formulas were derived that roughly approximate to the most important stress values As will be shown in section III with these formulas a direct relation can be established between the most important design and material parameters and some aspects of the mechanical performance of the system

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Ducheyne P Kagan II A and Lacy J A (1978) Failure of total knee arthroplasty due to loosening and deformation of the tibial component J Bone Jt Surg Vol 60-A pp 384-391

Eftekar M S Kierman H A Jr and Stinckfield S E (1976) Systemic and local complications following low friction arthroplasty of the hip joint Arch of Surg vol 111 p 150

Feith R (1975) Side effects of acrylic cement implanted into bone Acta Orthop Scand Suppl nr 161

Feith R Slooff T J J H Kazem I and van Rens Th J G (1976) Strontium 87m Sr bone scanning for the evaluation of total hip replacement J Bone Jt Surg 58 B 79 83

Freeman M A R Todd R C Bamert P and Day W H (1978) ICLH arthroplasty of the knee 1968 1977 J Bone Jt Surg Vol 60-B no 3 pp 339 341

Galante J O Rostoker W and Doyle J M (1975) Failed femoral stems in total hip prosthesis J Bone Jt. Surg 57 A no 2 230

Green D L (1976) Complications of total hip replacement South Med J 69 1559

Griss P Heimke G Werner, E Bleicher J and Jentschwa G (1978) Was bedeutet die Resorption des Calcar Femoris nach der Totalendoprothesenoperation der Hufte Arch Orthop Traumat Surg 92 225 232

Gruen T and Amstutz H C (1977) Mechanical modes of failure of femoral components – radiographic examination of total hip replacement 22nd National SAMPE Symp vol 22 Soc for the Adv of Mat and Process Eng San Diego Cal April

Gschwend N (1976) Symposium on total prostheses clinical material and over all results In Total hip prosthesis (Gschwend and Debrunner eds) Hans Huber Publ Bern Stuttgart Vienna

Halawa M Lee A J C Ling R S M and Vangala S S (1978) The shear strength of trabecular bone from the femur and some factors affecting the shear strength of the cement bone interface Arch Orthop Traumatol Surg 92 pp 19 30

Hench L L Pantano C G Bussemi P J and Greenspan D C (1977) Analysis of bioglass fixation of hipprostheses J Biomed Mat Res 11 2 pp 267 283

Hoogbergen T J M van Rens Th J G and Huiskes R (1975) A long term follow up study of patients with hemiarthroplasty of the hip with respect to protrusio of the prosthesis In Controversial opinions selected proceedings IX Europ Fed Congr of Surgeons (Greep *et al* eds)

Huiskes R and van Heugten P C M (1974) A discussion of problem solving methods in biomechanical research In Proceedings of the Combined Meeting of the Dutch and Danish Orthopaedic Societies (Biermans *et al* eds) Univ of Nijmegen The Netherlands

Hunter G A and Dandy D (1977) The natural history of the patient with an infected total hip replacement J Bone Jt Surg 59 B 293

Koch J C (1917) The laws of bone architecture Am J Anat vol 21

Kolbel R Bergmann G and Boenick U (1976) Mechanical properties of the cement/bone bond In Advances in artificial hip and knee joint technology (M Schaldach D Hohmann eds) Springer Verlag Berlin Heidelberg New York

Krause W R Miller J E and Ng W W P (1979) Penetration of acrylic bone cement into cancellous bone 25th Ann ORS San Francisco Cal February

Kusy R P (1978) Characterization of self-curing acrylic bone cements J Biomed Mat Res. Vol 12 pp 271 305

Kutzner F Dittmann E C H and Ohnsorge J (1974) Restmonomerabgabe von abharten den Knochenzement Experimentelle Untersuchungen Arch Orthop Unfall-Chir 79 247 253

Lacey J A. (1978) A statistical review of 100 consecutive U C I low friction knee arthroplasties with analysis of results Clin Orthop Rel Res 132 163

REFERENCES

Amstutz, H C (1970), Complications of total hip replacement, Clin Orthop Rel Res 72 123

Amstutz H C, Green, R A Markolf, K L and McNeice, G M (1976), Loosening of total hip components, cause and preventions, In The Hip, Proc Hip Society, C V Mosby, St Louis

Beckenbaugh, R D and Ilstrup D M (1978), Total hip arthroplasty, a review of three hundred and thirty three cases with long follow up, *J Bone Jt Surg 60 A, no 3 306*

Bergstroem, B, Lindberg L, Persson, B M and Oennerfaelt R (1973), Complications after total hip arthroplasty according to Charnley in a Swedish series of cases, Clin Orthop Rel Res 95 91

Bocco, F Langan, P and Charnley, J (1977), Changes in the calcar femoris in relation to cement technology in total hip replacement, Clin Orthop Rel Res 128, 287 295

Brewster, R C, Chao, E Y and Stauffer, R N (1974), Force analysis of the ankle joint during the stance phase of gait, 27th ACEMB, Philadelphia, p 369 *proceedings*

Chao E Y (1976), The biomechanics of total joint replacement surgery, Geriatrics, March

Chao, E Y (1979), *private communication*

Charnley J (1970), Acrylic cement *in orthopaedic surgery*, E and S Livingstone, *Edinburgh and London*

Charnley, J and Cupic, Z (1973), The nine and ten year results of the low friction arthroplasty of the hip Clin Orthop Rel Res 95 9 25

Charnley J (1975), Fracture of femoral prostheses in total hip replacement, Clin Orthop Rel Res 111 105

Charnley J and Halley D K (1975) The rate of wear in total hip replacement Clin Orthop Rel Res 112 170

Charnley, J (1977) Prosthetic fixation and loosening 3rd Annual Meeting Soc for Biomaterials New Orleans La April

Charnley J (1978) Low friction arthroplasty of the hip Springer Verlag Berlin Heidelberg, New York

Collis D K (1977), Femoral stem failure in total hip replacement J Bone Jt Surg 59 A, no 2 1033

Debrunner H U Wettstein A and Hofer P (1976) The polymerization of selfcuring acrylic cements and problems due to the cement anchorage of joint prostheses, In Advances in Artificial Hip and Knee Joint Technolgy (Schaldach M and Hohmann D, eds) Springer Verlag Berlin, Heidelberg, New York

Diehl K (1975), Knochenbeanspruchung und Knochenumbau bei der Alloplastik des coxalen Femurendes mit Zement verankerung, Arch Orthop Unfall-Chir 83 9 23

Dietschi C Huggler A and Suezawa Y (1976) *Problems of loosening In Total hip prosthesis* (Gschwend and Debrunner eds) *Hans Huber Publ Bern Stuttgart Vienna*

Dobbs (1977), *A model to predict the incidence of tracture in femoral components J Bioeng vol 1, pp 189 196*

Ducheyne, P, Meester, P de Aernoudt E Martens, M and Mulier, J C (1975) Fatigue *fractures of the femoral component of Charnley and* Charnley Muller type total hip prostheses, J Biomed Mat Res Symp No 6 pp 199 219

Ducheyne P, *Aernoudt E de Meester P Martens M*, Mulier, J C and van Leeuwen D (1977) Factors governing the mechanical behaviour of the implant porous coating trabecular *bone interface J Biomech* Vol 11, pp 297 307

Rhinelander F W (1972) Circulation in bone In The Bioschemistry and Physiology of bone (G H Bourne ed) 2nd ed vol II Academic Press New York
Rhinelander F W (1979) Personal communication 5th Ann Meeting Soc for Biomaterials Clemson So Car April May
Rostoker W Chao E Y S and Galante J O (1978) Defects in failed stems of hip prostheses J Biomed Mat Res vol 12 635 651
Rostoker W and Galante J O (1979) Materials for human implantation ASME J Biomech Eng vol 101 Febr pp 2 14
Rutt A (1977) Zur Aetiopathogenese der aseptischen Auslockerung von Huftgelenktotal endoprothesen Arch Orthop Unfall-Chir 88 139
Rydell N W (1966) Forces acting on the femoral head prosthesis Acta Orthop Scand Suppl 88 vol 37
Salvati E A Chuem Jm V Aglietti P and Wilson P D (1976) Radiology of total hip replacements Clin Orthop Rel Res 121 74
Schlein A P (1976) Semi constraint total elbow arthroplasty Clin Orthop Rel Res No 121 p 222
Schulitz K.P and Dustmann H O (1976), Komplikationen der Totalendoprothese Arch Orthop Unfall-Chir 85 33 50
Scott R D Turner R H Leitzes S M and Aufranc O E (1975) Femoral fractures in conjunction with total hip replacements J Bone Jt Surg 57 A no 4 494
Seireg A and Arvikar R J (1975) The prediction of muscular load sharing and joint forces in the lower extremities during walking J Biomech 8 89
Slooff T J J H (1969) A cement syringe Acta Orthop Belg 35 1012 1014
Slooff T J J H (1970) De invloed van het acryl cement bij de fixatie van de heupprothese Dissertation Univ of Nijmegen The Netherlands
Slooff T J J H Schaapsmeerders F v d Sandt H A and van Rens Th J G (1976) Treatment of 40 loosened total hip replacements Acta Orthop Belg 42 492 500
Spector M Michno M J Smarook W H and Kwiatkowski G T (1978) A high modulus polymer for porous orthopaedic implants Biomechnical compatability of porous implants J Biomed Mat Res vol 12 665 677
Stuhmer G (1976) Loosening of prostheses In Total hip prosthesis (Gschwend and Debrunner eds) Hans Huber Publ Berlin Stuttgart Vienna
Swansson S A V and Freeman M A R (1977) The scientific basis of joint replacement Pitman Med Publ Comp Tunbridge Wells
Trommsdorf E (1963) Polymerisate der Acrylsaure ihrer Homologe und Derivate In (Houwink R und Stavermann A J eds) Chemie und Technologie der Kunststoffe Bd II/I Akad Verlagsges Leipzig 541 599
Vernon Roberts B and Freeman M A R (1976) Morphological and analytical studies of the tissue adjacent to joint prostheses In Advances in artificial hip and knee joint technology (Schaldach and Hohmann eds) Springer Verlag Berlin Heidelberg New York
Vernon Roberts B and Freeman M A R (1977) The tissue response to total joint replace ment prostheses In The scientific basis of joint replacement (S A V Swansson and M A R Freeman eds) Pitman Med Publ Comp Tunbridge Wells.
Visuri T Salenius P and Laurent L E (1977) Total hip replacement by the Brunswick prosthesis Acta Orthop Scand vol 48 no 1 pp 197 203
Visuri T and Laurent L E (1977) Results of revision operations of loosened and infected total hip prosthesis Acta Orthop Scand vol 48 no 3 p 229
Volz R G and Gradillas E L (1978) Thermal deformation of Polyethylene in a total knee prosthesis J Bone Jt Surg 60-A no 5 662

Lautenschlager, E P , Moore, B K and Schoenfeld, C M (1974), Physical characteristics of setting acrylic bone cements, J Biomed Mat Res Symp Vol 8, no 5, Part I, pp 185 196

Lazansky, M G (1973), Complications revisited, Clin Orthop Rel Res , 95, 96 103

Lee, A J C , Ling, R S M and Vangala, S S (1977), The effect of implant design on fixation and performance, 3rd Annual Meeting Soc for Biomaterials, New Orleans, La , April

Lee, A J C , Ling, R S M and Vangala, S S (1978), Some clinically relevant variables affecting the mechanical behaviour of bone cement, Arch Orthop Traumatol Surg 92, 1 18

Maier, S , Griss, P , Rahmfeld, P and Binkelacker, P (1977), Nachuntersuchungsergebnisse der totalen Alloarthroplastiek der Hufte unter besonderer Berucksichtigung der Spät komplikationen, Z f Orthop u Grenzgebiete, Band 115, pp 274-283

Markolf, K L and Amstutz, H C (1976), In vitro measurements of bone acrylic interface pressures during femoral prosthesis insertion, 22nd Annual ORS, New Orleans, Louisiana, January

Martens, M , Aernoudt, E , de Meester, P , Ducheyne, P , Mulier, J C , de Langh, R and Kestelijn, P (1974), Factors in the mechanical failure of the femoral component in total hip prosthesis, Acta Orthop Scand 45, 593 670

McElfresh E C and Coventry M B (1974), Femoral and pelvic fractures after total hip arthroplasty, J Bone Jt Surg 56 A, no 3 483

Miller, J , Burke, D L , Stachiewicz, J W and Kelebay L (1976), A study of the interface between polymethylmethacrylate and living cortical bone under conditions of load bearing, 22nd Ann ORS, New Orleans, La , January

Miller, J , Burke D L Krause W , Ahmed A and Kelebay, L C (1978), Blood and surgical debris on the surface of medullary canal bone as a factor in the loosening of hip arthro plasty components 24th Annual ORS Dallas, Texas February

Mohr, H J (1958), Pathologische Anatomie und kausale Genese der durch selbst polymeri sierendes Methacrylat hervorgerufenen Gewebsveranderungen, Z ges exp Med 130 41 49

Muller, K (1975), Grundsatzliches Verhalten von Knochenzementen aus stoff technischer Sicht, In Die Knochenzemente (Oest *et al* eds), Ferd Enke Verlag, Stuttgart

Muller, K (1979) A practice oriented study of the complex Processing and Handling Application Resultant Properties of autopolymerizing PMMA bone cements, Z Werk stofftechn 10, pp 30-36

Muller, M E (1974) In Zeitschrift f Orthop 1977 band 115 p 274 283

Muller M E (1976), Complications of total hip replacement In Total hip prosthesis (Gschwend and Debrunner eds) Hand Huber Publ Bern Stuttgart Vienna

Muller M E and Niederer, P (1977) Design performance and fracture of femoral stem components 3rd Annual Meeting Soc for Biomaterials New Orleans La April

Narten N C Larke D Greenwald A S and Wilde, A H (1977) paper 32 30th ACEMB Los Angeles, Cal Nov

Nederpelt, K J (1978), private communication

Oest, O Muller, K und Hupfauer W (1975) Die Knochenzemente Ferd Enke Verlag Stuttgart

Oh, J , Carlson, C E Tomford W W and Harris W H (1978), Improved fixation of the femoral component after total hip replacement using a methacrylate intramedullary plug J Bone Jt Surg vol 60-A no 5, 608 613

Paul J P (1974), Force actions transmitted in the knee of normal subjects and by prosthetic joint replacement Inst Mech Eng Conf on Total Knee Repl London Sept

Peterson L S A (1977) Current status of total knee arthroplasties, Arch Surg vol 112 pp 1099 1104

SECTION TWO

HEAT GENERATION AND CONDUCTION ANALYSES OF ACRYLIC BONE CEMENT IN SITU

Walker, P S (1977), Human joints and their artificial replacements, Charles C Thomas, Publ , Springfield, Ill
Weber, F A and Charnley, J (1975), *A radiological study of fractures of acrylic cement in relation to the stem of a femoral head prosthesis*, J Bone Jt Surg 57 B no 3
Weber, B G and Stuhmer, G (1979), Improvements in total hip prosthesis implantation technique, Arch Orthop Traumatol Surg 93, pp 185 189
Willert, H G and Puls, P (1972), Die Reaktion des Knochens auf Knochenzement bei der *Allo Arthroplastik der Hufte, Arch Orthop Unfall Chir 72, 33 71*
Willert, H G , Ludwig, J and Semlitsch, M (1974), Reaction of bone to methacrylate after hip arthroplasty, J Bone Jt Surg 56 A, 1368 1382
Willert, H G and Frech, H A (1976), Tissue damage caused by bone cement, In Advances *in artificial hip and knee joint technology (N Schaldach and D Hohmann, eds), Springer Verlag, Berlin, Heidelberg, New York*
Willert, H G and Semlitsch, M (1976), Problems associated with the cement anchorage of artificial joints, In Advances in artificial hip and knee joint technology (N Schaldach and D Hohmann, eds), Springer Verlag, Berlin Heidelberg, New York
Willert, H G , Semlitsch, M , Buchhorn, G and Kriete, U (1978), Materialverschleiss und Gewebereaktion bei kunstlichen Gelenken, Orthopade 7, 62 83
Witt, A N N and Hackenbroch M H (1976), Therapeutische Moglichkeiten bei gelockerten Hufttotalprothesen, Z Orthop , 114, 330-341
Wijn, de J R (1974), Reduction of maximum temperature in the polymerization of cold *and heat curing acrylic resins, J Biomed Mat Res , vol 8, 421 434*
Wijn, de J R , Driessens, F C M and Slooff T J J H (1975), Dimensional behaviour of curing bone cement masses, J Biomed Mat Res Symp no 6, 99 103
Wijn, de J R , Ypma, J , Huiskes R , van Mullem, P J and Slooff, T J J H (1977) Stress relaxation and dynamic experiments with massive and porous bone cements, 1e Europ Conf on Evaluation of Biomaterials, Strasbourg, Sep t
Wijn, de J R , Mullem, P J van, Ypma, J , Huiskes R and Slooff, T J J H (1978), Development of polymethylmethacrylate aqueous gel bone cement, parts I and II, Report Cement Group, Lab Exp Orthop and Lab Dent Mat Res , Univ of Nijmegen The Netherlands
Ypma, J , Wijn, J R de, Huiskes, R and Slooff, T J J H (1979) Strength and ingrowth aspects of porous acrylic bone cements, 5th Ann Meeting Soc of Biomaterials So Car , April May

CONTENTS

Geometry and materials quantities

m	kg	mass
V	m^3	volume
ν	—	volume fraction (see paragraph 5 1)
P/L	gr/cc	powder to liquid ratio
r_u	m	outer bone radius
r_i	m	inner bone radius
s	m	cement layer thickness
r_s	m	implant stem radius
μ	—	weight ratio m_{ap}/m_p

Materials properties

λ	J/msec°C	thermal conductivity
C	J/m³°C	heat capacity
c	J/kg°C	specific heat
ρ	kg/m³	density

Heat generation

$\Phi(r\ z\ t)$	J/m³sec	heat source
$\Phi_n(r\ z)$ $\Phi_{n-1}(r\ z)$ etc	J/m³sec	heat source at time t_n t_{n-1} etc
Q	J/m³	*heat generation per unit volume of acrylic cement*
Q_t	J/kg	heat generation per unit mass of monomer
ρ_m	kg/m³	density of monomer
ν_m	—	volume fraction of actually polymerizing monomer in the cement mixture
$p(t)$	—	polymerized fraction of the monomer (polymerization function)
t_r	sec	retardation time (see paragraph 5 2)
τ	sec	polymerization time (see paragraph 5 2)
θ_p	sec^{-1}	maximal polymerization rate

Others

$q(r\ z\ t)$	J/m²	heat flow
α	J/m²sec°C	surface conduction and convection coefficient
β_{kl}	J/m²sec°C	thermal contact (interface) conductivity from material k to material l
t_e	sec	time of exposure
$T_n(t_e)$	C	threshold temperature for cell necrosis
$T_d(t_e)$	°C	*threshold temperature for vascular damage*

LIST OF SYMBOLS

General

t	sec	time
t_n t_{n-1}, etc	sec	times
Δt	sec	time step ($t_n - t_{n-1}$)
r, z	m	coordinates (cylindrical system)
x, z	m	coordinates (plane rectangular system)

Temperature

$T(r,z,t)$	°C	temperature
$T_n(r,z)$, $T_{n-1}(r,z)$, etc	°C	temperature at time t_n t_{n-1} etc
$T_a(r,z)$	°C	ambient temperature
$T_0(r,z)$	°C	initial temperature
T_{0j}	°C	initial temperature of material j (for possibilities of j see under indices)
$\Delta T(r\ z,t)$	°C	temperature drop
$T_{max}(r\ z)$	°C	maximal temperature
T_b	°C	maximal bone temperature
ΔT_b	°C	maximal bone temperature increase (T_b-37°C)
T_c	°C	maximal cement temperature
ΔT_c	°C	maximal cement temperature increase ($T_c - T_{0c}$)
$\delta(t)$	mm	penetration depth (in the bone) of an isotherm
δ_m	mm	maximal penetration depth (in the bone) of the 50°C isotherm

Indices

The indices used for the parameters describing the materials properties and quantities (and some other parameters) refer to

c – cement
i – implant
b – bone
p – polymer
m – the actually polymerizing monomer
rm – residual monomer
po – powder
li – liquid
ap – additives to the polymer
am – additives to the monomer
ac – additives to the cement mixture

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$\Phi(r,z,t)$	$J/m^3 sec$	heat source
$\Phi_n(r,z)$, $\Phi_{n-1}(r,z)$ etc	$J/m^3 sec$	heat source at time t_n, t_{n-1} etc
Q	J/m^3	heat generation per unit volume of acrylic cement
Q_1	J/kg	heat generation per unit mass of monomer
ρ_m	kg/m^3	density of monomer
ν_m	-	volume fraction of actually polymerizing monomer in the cement mixture
$p(t)$	–	polymerized fraction of the monomer (polymerization function)
t_r	sec	retardation time (see paragraph 5 2)
τ	sec	polymerization time (see paragraph 5 2)
θ_p	sec^{-1}	maximal polymerization rate

Others

$q(r,z,t)$	J/m^2	heat flow
α	$J/m^2 sec^\circ C$	surface conduction and convection coefficient
β_{kl}	$J/m^2 sec^\circ C$	thermal contact (*interface*) conductivity from material k to material l
t_e	sec	time of exposure
$T_n(t_e)$	°C	threshold temperature for cell necrosis
$T_d(t_e)$	°C	threshold temperature for vascular damage

LIST OF SYMBOLS

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t	sec	time
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ap — additives to the polymer
am — additives to the monomer
ac — additives to the cement mixture

Authors	maximal cement bone interface temperature	conditions
Homsy *et al* (1972)	70 90°C	dog femurs various bone cements
Meyer *et al* (1973)	70°C	human femurs total hip replacement
Biehl *et al* (1974)	47°C	average value human femur, total hip replacement
Labitzke and Paulus (1974)	45°C	average value, human femur total hip replacement

table 2 1 Results of some temperature measurements in vivo at the cement bone interface as reported in the literature

conclusions as to whether the reported temperatures are those of the cement or the bone

Another kind of experiment in vivo was reported by d Hollander *et al* (1976) who measured temperatures during total hip replacement at the outside surface of the femur and in the bloodstream of the ipsilateral iliac vein The first quantity increased from an average of 31 5°C to one of 34 1°C the latter remained practically stable at an average of 34 5 C

2.2 Temperature measurements in vitro

Ohnsorge and Kroesen (1969) measured temperatures as a function of time in the centre and at the surface of a ball of acrylic cement curing in free air in the laboratory They established maximal values of 122°C in the centre and 92°C at the surface Comparable experiments carried out by Hupfauer and Ulatowski (1972) resulted in maximal temperature values of up to 134 C it is not clear what causes the discrepancy between these results and those of Ohnsorge and Kroesen (1969) Hupfauer and Ulatowski (1972) in addition measured temperatures in plates of bone cement using thermography Although this method is not very accurate the results clearly indicate that the temperature values were distributed rather inhomogeneously over the surface of the plate

Ohnsorge and Goebel (1969 1970) measured temperatures at different locations during fixation of a hip endoprosthesis in a cadaveric femur An example of their results which are rather illustrative is shown in fig 2 1 They repeated this experiment after pre cooling the prosthesis to 0 C The maximal interface temperature in this case was about 20° less However due to pre cooling the setting time of the cement approximately doubled which probably results in inferior mechanical properties (Oest *et al*, 1975)

Meyer *et al* (1973) measured temperatures in acrylic cement curing in a Teflon cup They varied the quantities used the powder to-liquid ratio and the initial temperature Their results will be used for an evaluation of the mathematical model applied here as will be described in chapter 6

Other temperature measurements in various circumstances were conducted by de Wijn (1974) Jefferiss *et al* (1975) Cameron *et al* (1975) Dipisa *et al* (1976) Debrunner *et al*

CHAPTER ONE

INTRODUCTION

In this section a mathematical (computer) model will be presented for the analysis of the heat generation and conduction process of self curing acrylic cement in situ The model will be used to simulate this process as it occurs during fixation of artificial joints, to predict time and location dependent temperature values in the bone prosthesis system The results will be compared with data on thermal damage threshold levels of bone tissue, as published in the literature, in order to assess the possibility of thermal necrosis The second chapter contains a review of the literature on previous work The third chapter treats possible threshold levels for thermal bone necrosis and in the fourth the model, its assumptions and the mathematical methods of solution will be discussed In chapter five values for para meters describing the heat generation and conduction properties of the system, to be used in the model calculations, will be estimated on the basis of a thorough review of the litera ture In order to evaluate the model and the method of analysis two experiments described in the literature are simulated, as described in chapter six In chapter seven the model is actually used to simulate the thermal behavior of the cement during fixation of intra medullary implants To establish the influences of the system properties, a parametric analysis with respect to this bone prosthesis system was carried out and will be described also in this chapter Chapter eight discusses the use of the acrylic cement during acetabular cup fixation and in chapter nine various measures that can be taken to reduce the chances of thermal bone necrosis are evaluated as to their effectiveness

CHAPTER TWO

A SHORT REVIEW OF THE LITERATURE ON EARLIER WORK

2 1 Temperature measurements in vivo

Several measurements of temperatures in the cement bone contact region (the interface') in vivo have been reported in the literature some of which are summarized in table 2 I
All investigators used thermocouples
Although these results give some indication of the temperature values that might occur there is some doubt as to their reliability The heat conduction process will certainly be affected by the thermocouples and, moreover, the cement bone interface is a region rather than a well defined location where a steep temperature gradient probably occurs Hence, the 'cement bone interface temperature is a badly defined quantity and measurements in this region will be highly sensitive to the thermocouple locations It is thus hard to draw

Such a simple model could be very valuable in roughly evaluating influences of some parameters however the parameter values they applied in their model for the heat capacity and conductivity properties of the materials were quite unrealistic
D'Souza *et al* (1977) calculated transient temperatures in an axisymmetric slice consisting of a metal core and a bony ring with acrylic cement in between Few data were published but they claim a good agreement between the results and those of verification experiments
A comparable analysis was carried out by Swenson *et al* (1976) who studied the influences of the cement layer thickness on the maximal bone temperatures In this case too few data were published

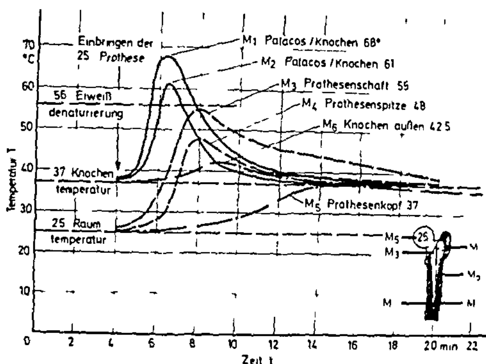


Fig 2 1 Temperatures as a function of time at 6 locations in a cadaveric femur prosthesis system during the polymerization of the acrylic cement (reproduced with permission of Ohnsorge and Goebel, 1969)

(1976), Lee and Turner (1977) and Seidel *et al* (1977) Varieties in commercial brands, influences of initial temperatures heat sink additives and the polymerization rate were studied in some of these experiments

Experimental conditions were usually much better defined in these laboratory measurements compared to the experiments in vivo and useful information was obtained on the thermal behavior of the curing acrylic cement Because of the empirical character of the experiments, however, it is often difficult to apply the results to the situation in vivo and derive general criteria for the use of the cement as so little is known about the influences of the different geometrical and material parameters Moreover also in these laboratory experiments the interface temperatures are unreliable, due to the thermocouple influence and the steep temperature gradient in this region
It has become clear from these experiments that the properties and the geometry of the adjoining materials have a significant influence on the temperature values and that the heat generation process can be affected by changing the composition of the cement mixture
It was also found that the initial temperature of the cement greatly influences the setting time

2 3 Theoretical studies

A theoretical study of the heat conduction process in acrylic cement was carried out by Jefferiss *et al* (1975) Their model is very simple assuming one dimensional heat flow and neglecting the time dependent character of the heat generation process (a homogeneous initial temperature was assumend in the cement layer)

Such a simple model could be very valuable in roughly evaluating influences of some para meters however the parameter values they applied in their model for the heat capacity and conductivity properties of the materials were quite unrealistic
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CHAPTER THREE

THRESHOLD LEVELS FOR THERMAL BONE NECROSIS

After temperature values in bone have been measured or calculated, they have to be compared to a thermal damage criterion in order to estimate the chances of thermal necrosis, such a criterion is called the temperature threshold level for thermal damage (here denoted by T_n(°C)) In the literature on thermal behavior of acrylic cement, as discussed in the previous chapter, the threshold temperatures of collagen denaturation (56°C, Lehnartz (1959), 60°C, Viidik (1972), 70°C, Labitzke and Paulus (1974)) is usually taken as a criterion It has been established, however, that collagen is more temperature resistent than the protoplasm proteins (Lundskog, 1972) In this respect Leach *et al* (1943), on the basis of an extensive review, concluded that all endothelial cells die at a temperature of 47°C and over and also that temperatures between 42°C and 47°C, provided they are maintained long enough, may harm the cells This was confirmed by Moritz (1947) and Sevitt (1957)
Not only the temperature, but also the time during which the tissue is exposed determines the threshold level for thermal damage, hence, this level will be time dependent ($T_n = T_n(t_e)$ where t_e is the time of exposure) Investigations on time dependent threshold curves for epithelial cells were carried out by Moritz and Henriques (1947) They established, for instance that a temperature of 70°C will kill the cells immediately, that a temperature of 55°C will do so after a 30 seconds, but that a temperature of 45°C would have to be maintained for more than 5 hours to harm the cell Based on these results they constructed a temperature threshold curve ($T_n(t_e)$) for epithelial cells Their results have been confirmed later by other investigators (as cited by Lundskog 1972), for human as well as for porcine skin Kuhl *et al* (1954) found a slightly lower threshold level for epidermal necrosis (52°C after 30 seconds) in mice experiments and ascribe the deviation to differences in the species

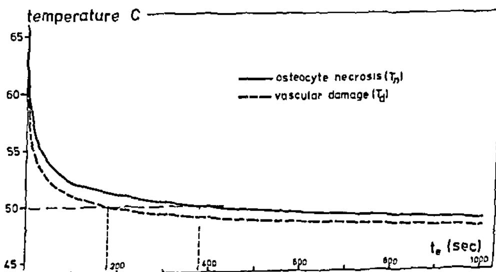


Fig 3 1 The time-dependent threshold level for cell necrosis (T_n), as established for epithelial cells by Moritz and Henriques (1947) and also the time-dependent threshold level for vascular damage (T_d), as constructed on the basis of data from the same authors t_e denotes the exposure time

Lundskog (1972) in extensive histochemical studies on rabbits roughly confirmed the threshold curve reported by Moritz and Henriques (1974) but established a lower threshold value for the bone cells using heated implants (50°C after 30 seconds) He also indicated that much higher temperatures (up to 70°C) are needed before damage is done to the regenerative capacity of the bone tissue

Due to the many parameters that are involved in experiments in vivo and also because of uncertainties as to the possible surgical trauma brought about by implants the results of Lundskog cannot be considered as significantly different from those of Moritz and Henriques

Because the threshold curve published by the last named authors gives a good impression of both the temperature and the time aspects of thermal necrosis it will be used here as a criterion for judging possible osteocyte necrosis

Moritz and Henriques (1947) also reported that there is functional damage to the vascularity after exposure periods that are about 40 to 60% shorter compared to the necrosis level of epithelial cells From this the vascular damage temperature threshold curve ($T_d(t_e)$) can be constructed Graphs for both T_n and T_d are shown in fig 3 1 It should be kept in mind however that cell necrosis has also been reported for lower temperatures (Lundskog 1972)

CHAPTER FOUR

A THEORETICAL ANALYSIS OF HEAT GENERATION AND CONDUCTION

4 1 Assumptions and simplifications

To develop a mathematical model for simulating the process of heat generation and conduction, the relevant properties of the system must be described with parameters In order to perform actual calculations these parameters must be given values Relatively little is known about parameter values for heat generation, heat conduction and heat capacity properties of the materials in the bone prosthesis system Hence, a very refined model can not actually be used It is also open to question in view of complicated aspects (for instance the structure of bone, the vascularity, the geometry of the cement bone interface and the consistency of the cement mantle, all of which vary considerably from patient to patient) whether a very refined model would be justified Therefore a number of assumptions are made In order to be able to analyse the thermal behavior of the cement using the classical heat conduction theory it is assumed

- no material transport takes place in the system, and the materials are incompressible
- the local heat loss by conduction and convection at the boundary of the system (usually the outer bone surface) is proportional to the difference in the local boundary temperature and a constant local ambient temperature, or the boundary temperature is equal to this ambient temperature

To simplify the analysis in view of the above mentioned aspects of the complicated bone prosthesis system, it is assumed that

- the thermal properties of implant, cement and bone are isotropic
- the cement mixture is homogeneous,
- the heat conduction and capacity properties of the materials are independent of the temperature
- the heat generation as a function of time is independent of the temperature,
- the cement bone interface is smooth and the local heat transport across the interface is proportional to the local difference in temperature between the two materials

Obviously, the results of the model calculations can only predict the temperature values in the real system by approximation Since influences of inaccuracies can be evaluated by parametric analyses, the model can still conveniently by used to obtain reliable approximative data if gross effects are not neglected due to the assumptions The most serious assumption in this respect as follows from the experimental data discussed in paragraph 2 2 is neglecting the temperature influences on the time dependent heat generation necessary because a mathematical description of this influence is not available There are indications, however (Naylor and Billmeyer 1953, Meyer *et al*, 1973 Debrunner *et al*, 1976) that this influence, which mainly affects the setting time of the cement is relatively slight provided the initial temperature variance of the cement is kept within a small range

The bone prosthesis systems to be investigated are approximated by axisymmetric or plane geometry, which simplifies the solution procedures to a great extent and will in most cases give quite realistic results It should be remarked here that the previously mentioned assumptions would not justify a true three dimensional model, as a model requires a certain balance in the description of all aspects Furthermore if the aim is to perform extensive parametric analyses and evaluate the influences of the most important system parameters in

order to develop a fundamental concept of the heat conduction process the number of parameters in the model have to be kept restricted

4 2. Mathematical formulation

In consequence of the previously mentioned assumptions the process of heat generation and conduction can be described with the heat conduction equation (Carlslaw and Jaeger, 1959) based on the conservation-of energy principle and Fourier s law of heat conduction Assuming an axisymmetric construction (fig 4 1) consisting of (for example) three

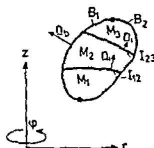


fig 4 1 An arbitrary axisymmetric structure consisting of three materials (see text)

materials (M_1 M_2 and M_3) in contact at the interfaces (I_{12} and I_{23}) with boundaries B_1 and B_2 the time and location dependent temperature $T(r\ z\ t)$ can be described by

$$\frac{\partial}{\partial r}\left(\lambda r\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(\lambda r\frac{\partial T}{\partial z}\right) - Cr\frac{\partial T}{\partial t} + r\Phi = 0 \qquad \text{in } M_1\ M_2 \text{ and } M_3 \qquad (4\ 1)$$

$$\lambda\,(\underline{n}, \mathrm{grad}T) = -\alpha(T - T_a) \qquad \text{on } B_1 \qquad (4\ 2)$$

$$T = T_a \qquad \text{on } B_2 \qquad (4\ 3)$$

$$\lambda(\underline{n}, \mathrm{grad}T) = -\beta(T - T_{adj}) \qquad \text{on } I_{12} \text{ and } I_{23} \qquad (4\ 4)$$

where

t	time	(sec)
$r\ z$	coordinates	(m)
$T(r\ z\ t)$	temperature	(°C)
$\Phi(r\ z\ t)$	heat source	(J/m³ sec)
$\lambda(r\ z)$	thermal conductivity	(J/msec°C)
$C(r\ z)$	heat capacity	(J/m³°C)
$\underline{n}(r\ z)$	normal vector on boundary (b) or interface (i)	(-)
$\alpha(r\ z)$	su face conduction and convection coefficient	(J/m² sec°C)
$T_a(r\ z)$	ambient temperature	(°C)

$\beta(r,z)$	interface conductivity	$(J/m^2 sec°C)$
$T_{adj}(r,z,t)$	temperature of the adjoining material	(°C)

with initial conditions $T(r,z,0) = T_0(r,z)$ in M_1, M_2 and M_3 and on B_1, B_2, I_{12} and I_{23}

For plane geometry (x z plane), assuming no heat flow in the direction perpendicular to the x z plane the differential equation transforms into

$$\frac{\partial}{\partial x}(\lambda\frac{\partial T}{\partial x}) + \frac{\partial}{\partial z}(\lambda\frac{\partial T}{\partial z}) - C\frac{\partial T}{\partial t} + \Phi = 0$$

while all other equations remain as they are, replacing r by x

4 3 Method of solution

The differential equation presented in the previous paragraph can not be solved analytically in general Hence, numerical (computer) methods have to be used In order to be able to take arbitrary geometry into account Finite Element Methods (FEM) offer the best options Different solution procedures are available (e g Zienkiewicz 1977) that can be divided into those that apply FE discretization in coordinates as well as in time, and those that apply FE discretization in geometry and a Finite Difference Method for discretization in time Because a computer program for the solution of elliptical differential equations (such as the heat conduction equation for steady state) in an arbitrary two dimensional region based on FEM was available (Brekelmans 1975), the latter method was chosen
The temperature as a function of time is discretized according to

$$\frac{\partial}{\partial t}T(t) \approx \frac{1}{\Delta t}\{T(t) - T(t-\Delta t)\} \qquad \text{(backward difference)}$$

where Δt denotes a time step

By introducing the notation $T_n(r,z) = T(r\ z\ t_n)$, $T_{n-1}(r\ z) = T(r\ z\ t_{n-1})$ $\Phi_n(r,z) = \Phi(r\ z,t_n)$ etc , where $\Delta t = t_n - t_{n-1}$ the equations (4 1) through (4 4) are approximated by respectively

$$\frac{\partial}{\partial r}(\lambda r\frac{\partial T_n}{\partial r}) + \frac{\partial}{\partial z}(\lambda r\frac{\partial T_n}{\partial z}) - \frac{C}{\Delta t}rT_n + \frac{C}{\Delta t}rT_{n-1} + r\Phi_n = 0 \qquad \text{in } M_1\ M_2\ M_3 \qquad (4\ 5)$$

$$\lambda(\underline{n},\text{grad}T_n) = -\alpha(T_n - T_a) \qquad \text{on } B_1 \qquad (4\ 7)$$

$$T_n = T_a \qquad \text{on } B_2 \qquad (4\ 8)$$

$$\lambda(\underline{n},\text{grad}T_n) = -\beta(T_n - T_{adj\ n}) \qquad \text{on } I_{12} \text{ and } I_{23} \qquad (4\ 9)$$

(4 5) is essentially an elliptical differential equation in T_n The available computer program for the solution of such an equation and the appropriate boundary conditions (Brekelmans 1975) was adapted to suit a step by step procedure in which for each step $(\frac{C}{\Delta t}rT_{n-1} + r\Phi_n)$ is a given quantity calculated from the previous step (Huiskes 1977)

This strategy could conveniently be followed by using the backward-difference formula for time discretization The application of this formula results in an unconditionally stable procedure according to Wilson *et al* (1966 1974), while the accuracy depends on the time step dimension In the computer program the time step is taken as constant because this greatly economizes the computer procedure The solution procedure cannot be qualified as efficient and better methods in this respect may be found in the literature (e g Zienkiewicz, 1977) However under the circumstances this choice has proved to be quite convenient and has given excellent results provided the time step dimension was small enough as was established in a number of test problems with known solutions (Huiskes 1977 1979b)
The element used in the FEM procedure is triangular and has *three nodal points* Within an element the temperature (T_n(r z)) is assumed to be linear in r and z The effects of the coarseness of the element mesh have also been studied in a number of tests (Huiskes 1977)

CHAPTER FIVE

REVIEW OF THE LITERATURE ON THERMAL PROPERTIES

5 1 The composition of the acrylic cement

The acrylic cement mixture is composed of polymer powder (PMMA) and monomer liquid (MMA) The composition of the mixture is expressed in the P/L ratio (gr polymer/cc monomer), which is usually around 2 An initiator is added to the powder and possibly radiopaque ($BaSO_4$ or ZrO_2) fillers or antibiotics A stabilizer and a catalyzer are added to the liquid The powder consists to approximately 99% of pure polymer, if no radiopaque or antibiotic additives are applied, and the liquid to approximately 97% of pure monomer After polymerizing about 2 5% residual monomer remains present in the cement (Charnley, 1970, de Wijn, 1974, Oest *et al*, 1975)

For convenience in later use, the following quantities are defined

m_c = mass of the cement mixture (kg)
V_c = volume of the cement mixture (m^3)
ρ_c = apparent density of the cement mixture (kg/m^3)

and further

m_i = mass of a component (kg)
V_i = volume of a component (m^3)
ρ_i = density of a component (kg/m^3)
ν_i = volume fraction of a component ($\nu_i = V_i/V_c$)

where i denotes p (polymer), m (the part of the monomer that actually polymerizes), rm (residual monomer), ap (additives to the polymer powder), am (additives to the monomer liquid), ac (additives to the cement mixture), po (powder component), li (liquid component)

The fraction of the monomer that actually polymerizes in the mixture can be calculated from

$$\nu_m = \frac{\rho_{po}}{\rho_{po} + P/L \times 10^3} + \nu_{rm} - \nu_{am} \qquad (5\ 1)$$

The density of the polymer is reported as $\rho_p = 1\ 18 \times 10^3\ kg/m^3$ (Charnley, 1970) and $P/L \approx 2$, if it is assumed that the residual monomer and the additives to the liquid each comprise approximately 3% of the liquid component it follows that $\nu_{rm} + \nu_{am} \approx 0\ 02$ The monomer fraction ν_m for given P/L ratio can be evaluated from fig 5 1, for which formula (5 1) was used

If a third component (ac) is added to the powder liquid mixture, the monomer fraction in the three component mixture can be calculated from

$$\nu_m = \nu_m\ (1 - \nu_{ac}) \qquad (5\ 2)$$

where ν_m denotes the monomer fraction in the original two component mixture

This formula (5 2) will be used in chapter 9

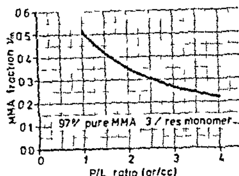


fig 5 1 Graphical representation of the relation between the P/L ratio and the actually polymerizing monomer volume fraction ν_m

5 2 Heat generation in acrylic cement

Heat is generated in the cement mass during the curing process due to the exothermic polymerization reaction of the monomer The total amount of heat generated per unit volume (Q) depends on the amount of monomer in the mixture and on the total amount of heat generated by the monomer per unit mass (Q_t)
It is obvious that both quantities are related by

$$Q = \nu_m \rho_m Q_t \qquad (J/m^3) \qquad (5\ 3)$$

It has been reported that $Q_t \approx 5\ 4 \times 10^5$ J/kg (e g Trommsdorf 1963) and $\rho_m \approx 0\ 94 \times 10^3$ kg/m^3 (e g Charnley 1970)

As the heat generated per unit time depends directly on the breakage of the double bond in the MMA molecules and hence on the amount of MMA molecules linked to PMMA per unit time the heat source or heat generation function $\dot{q}$ (t) is proportional to the rate of polymerizing
The polymerization process is for our purpose described by the polymerization function p(t) ($0 \leq p \leq 1$) giving the fraction of the monomer that has polymerized at a certain time Hence it follows that

$$\dot{q}(t) = \nu_m \rho_m Q_t \frac{dp}{dt} \qquad (J/m^3 sec) \qquad (5\ 4)$$

The polymerization function can be measured by using light refraction methods (e g Naylor and Billmeyer 1953) or by measuring the volumetric change of the mixture The latter method was used by de Wijn (1977) fig 5 2 shows an example of his results The shape of this curve is very typical of these functions in general although variations in setting time usually occur For our purposes the polymerization time τ (sec) is defined as the time from the beginning of the polymerization process until 75% of the monomer has polymerized The beginning of the process is usually somewhat retarded by the stabilizer, this period is called the retardation time (t_r(sec)) Usually $t_r \approx 100$ 200 sec and $\tau \approx 200$ 400 sec for bone cements
It is assumed here that the curve shown in fig 5 2 is in dimensionless form valid for all bone cements this curve is described by $p_1 = p_1(t\ t_r/\tau)$ $t \geq t_r$ and is in this form only influenced by t_r and τ

CHAPTER FIVE

REVIEW OF THE LITERATURE ON THERMAL PROPERTIES

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and further

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V_i =	volume of a component	(m^3)
ρ_i =	density of a component	(kg/m^3)
ν_i =	volume fraction of a component ($\nu_i = V_i/V_c$)	

where i denotes p (polymer) m (the part of the monomer that actually polymerizes), rm (residual monomer), ap (additives to the polymer powder) am (additives to the monomer liquid), ac (additives to the cement mixture), po (powder component) li (liquid component)

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$$\nu_m = \nu_m (1 - \nu_{ac}) \quad (5\ 2)$$

where ν_m denotes the monomer fraction in the original two component mixture

This formula (5 2) will be used in chapter 9

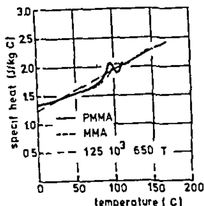


fig 5 3 Temperature-dependent heat capacities of MMA and PMMA as established by Hoffmann (in Oest et al 1975) and linear approximation

If $\nu_{ac} = 0$ it follows assuming $C_p \approx C_m$ that

$$C_c \approx C_p + (1 - \nu_m)(C_{ap} - C_p) \frac{\mu}{\rho_{ap}/\rho_p + \mu} \tag{5 6}$$

where

$\mu = m_{ap}/m_p$

If $\nu_{ap} = 0$ it follows that

$$C_c \approx C_p + \nu_{ac}(C_{ac} - C_p) \tag{5 7}$$

Formulas (5 6) and (5 7) will be used in chapter 9

The heat capacity of the cement mixture C_c will apart from a temperature dependency owing to c_p and c_m also be affected by dimensional changes due to the contraction of the monomer during the polymerization process
Taking both effects into account it follows that

$$C_c(t) \approx \{1\ 25 \times 10^3 + 6\ 5T(t)\} \{\rho_p + \nu_m(1 - p(t))(\rho_m - \rho_p)\} \tag{5 8}$$

If the cement mixture polymerizes adiabatically (ideally isolated) the temperature T(t) in the mass is described by

$$C_c \frac{dT}{dt} = Q \frac{dp}{dt} \tag{5 9}$$

By calculation of T(t) using the polymerization function $p_1(t)$ for a constant value of C_c as well as for C_c according to formula (5 8) it was shown that a good agreement between the two cases results if the (constant) heat capacity is taken as $C_c \approx 1\ 9 \times 10^6$ J/m³°C (Huiskes 1978) The estimated heat capacity values are summarized in table 5 I

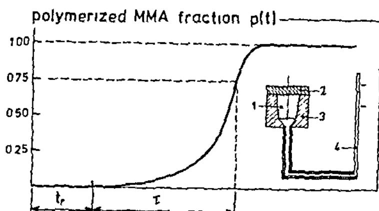


fig 5 2 The polymerization function p(t) as measured by de Wijn (1977) in shrinkage tests using the apparatus shown in the inset, 1 cement mass, 2 Delrin lid, 3 Delrin cup, 4 glass tube filled with liquid to register the amount of shrinkage In dimension less form ($p_1 = p_1(t\ t_r/\tau)$) this curve is assumed to be valid for acrylic cement in general

It should be remarked here that *slightly different curves (p_2 and p_3) will also be investigated* later

5 3 Heat capacity and conductivity properties

The heat capacity $C(J/m^{3\circ}C)$ of a material can be calculated from $C = \rho c$ where c = specific heat ($J/kg^{\circ}C$) ρ = density (kg/m^3)
The thermal conductivity of a material is denoted by λ ($J/msec^{\circ}C$) These symbols are applied with indices e g c_i ρ_i λ_i where i denotes the material (c (cement mixture) b (bone) etc)
In general c ρ and λ may depend on the temperature and on phase transitions but, as discussed in chapter 4 these dependencies will be neglected in the analyses

5 3 1 *Acrylic cement*

Kaye and Laby (1959) and Debrunner *et al* (1976) give for the specific heat of PMMA $c \approx 1\ 46x10^3 J/kg^{\circ}C$ *Hoffmann (cited by Oest et al, 1975) investigated the temperature* dependency of c with respect to PMMA as well as MMA fig 5 3 shows the results of this *study There appears to be little difference in the values for both materials Both curves can* be approximated by $c_m \approx c_p \approx 1\ 25x10^3+6\ 50T$ $(0 \lesssim T \lesssim 100)$
Values for the specific heat and the density of radiopaque additives, as given by Muller (1975) are shown in table 5 1

The heat capacity of the cement mixture can be calculated from

$$C_c = \nu_p C_p + \nu_m C_m + \nu_{ap} C_{ap} + \nu_{ac} C_{ac} + \nu_{am} C_{am} + \nu_{rm} C_{rm} \qquad (5\ 5)$$

the last two terms of which may be neglected

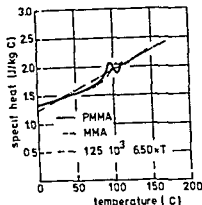


fig 5 3 Temperature-dependent heat capacities of MMA and PMMA as established by Hoffmann (in Oest et al, 1975) and linear approximation

If $\nu_{ac} = 0$ it follows assuming $C_p \approx C_m$ that

$$C_c \approx C_p + (1 - \nu_m)(C_{ap} - C_p)\frac{\mu}{\rho_{ap}/\rho_p + \mu} \qquad (5\ 6)$$

where

$\mu = m_{ap}/m_p$

If $\nu_{ap} = 0$ it follows that

$$C_c \approx C_p + \nu_{ac}(C_{ac} - C_p) \qquad (5\ 7)$$

Formulas (5 6) and (5 7) will be used in chapter 9

The heat capacity of the cement mixture C_c will apart from a temperature dependency owing to c_p and c_m also be affected by dimensional changes due to the contraction of the monomer during the polymerization process
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$$C_c(t) \approx \{1\ 25\times10^3 + 6\ 5T(t)\}\ \{\rho_p + \nu_m(1 - p(t))\,(\rho_m - \rho_p)\} \qquad (5\ 8)$$

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	density kg/m^3	specific heat J/kg°C	heat capacity J/m^3°C
PMMA	1 19x10^3	1 6x10^3 (50°C)	1 9x10^6 (50°C)
MMA	0 94x10^3	1 6x10^3 (50°C)	1 5x10^6 (50°C)
$BaSO_4$	4 50x10^3	0 43x10^3	1 96x10^6
ZrO_2	5 60x10^3	0 70x10^3	3 91x10^6
Acrylic cement	1 1x10^3	1 7x10^3	1 9x10^6

table 5 I Approximate values for heat capacity parameters of bone cement and its possible components

No investigations are known on the thermal conductivity of acrylic cement For PMMA a value of approximately 0 17 J/msec°C has been reported (Barrett *et al*, 1953, Frados, 1966)

5 3 2 *Implant materials*

Heat capacity and conductivity properties of a few industrial materials, relevant for the analyses, are summarized in table 5 II

	density kg/m^3	spec heat J/kg°C	heat capacity J/m^3°C	therm cond J/msec°C	source
Cr Ni steel	7 8x10^3	0 46x10^3	3 6x10^6	14	Eckert and Drake (1972)
HDPE	0 96x10^3	2 22x10^3	2 06x10^6	0 29	Kaye and Laby (1959)
Teflon	2 2x10^3	1 04x10^3	2 29x10^6	0 23	Kaye and Laby (1959)

table 5 II Thermal properties of some industrial materials

5 3 3 *Bone*

Measurements of thermal properties of various soft tissues in the body have been carried out by several investigators (e g *Balasubramanian et al*, 1977) data on bone are scarce however and the values available show a considerable scatter
No doubt the properties greatly depend on the macroscopic structure, either trabecular (spongeous) or cortical (compact) the microscopic structure for example orientation and coarseness of the bone matrix the fat content, the water content, and the macroscopic and microscopic vascularity Hence great individual differences probably occur while properties *in vivo*, too may differ from those of cadaveric material
Values for the heat capacity properties, as reported in the literature are summarized in table 5 III

Author	ρ_b (kg/m³)	c_b(J/kg°C)	C_b(J/m³°C)	test object
Henschel (1943)	2 1x10³	1 26x10³	2 65x10⁶	Fresh cortical bone (human)
Lundskog (1972)	–	1 26x10³	–	Fresh cortical bone (human)
Clattenburg *et al* (1975) (1)	2 1 2 3x10³	1 15 1 73x10³	2 64-3 64x10⁶	Fresh spongeous bone (calf)
Kummer (1972)	2 2 2 9x10³	–	–	Fresh cortical bone (human)
Saulgozis *et al* (1974)	1 86 1 93x10³	–	–	Fresh cortical bone (human)

table 5 III Heat capacity of cortical and spongeous bone as reported in the literature (1) Only C_b originally published values of ρ_b supplied by Cohen (1978)

Values for the thermal conductivity have been measured in different circumstances a summary of literature data is shown in table 5 IV

Source	λ_b(J/msec°C)		test object
Chato (1965)	0 38		Fresh cortical bone (human)
Vachon *et al* (1967)	2 3	(1)	In vivo cortical bone (bovine) 37 C
Vachon *et al* (1967)	0 6	(1)	Fresh cortical bone (bovine)
Lundskog (1972)	19	(2)	Fresh cortical bone (various mammals)
Lundskog (1972)	4	(2)	Dried cortical bone (various mammals)
Graf and Stein (1957)	0 36 0 60		In vivo spongeous bone (human) 37 C
Graf and Stein (1957)	0 29 0 43		Fresh spongeous bone (human) 37°C
Sundén (1967)	0 53		In vivo spongeous bone (rabbit) 37°C
Clattenburg *et al* (1975)	0 26-0 33	(3)	*Fresh spongeous bone (calf) 25°C*
Bowman *et al* (1979)	0 39		Fresh spongeous bone (human) 37°C

table 5 IV Values of λ_b as reported in the literature (1) Measurements on the outside bone surface, (2) unreliable technique gross effects of evaporation (3) isotropic pro perties established at 60°C about 15% higher values

With regard to the thermal conductivity apparently the greatest range in values is found for cortical bone but the experiments of Lundskog (1972) can be qualified as definitely unreliable and the measurements of Vachon *et al* (1967) as possibly unreliable because of the rough technique and influences of the sub periosteal vascularity at the outside surface of the bone Altogether it appears that presently λ_b for wet cortical bone should be

assumed as approximately 0 4 J/msec°C, for spongeous bone in vivo from 0 36 to 0 60 J/msec°C Since the experiments by Graf and Stein (1957) were carried out in vivo and in vitro in the same kind of bone (sternum) using the same technique, the differences reflect the influence of the vascularity

As regards the influence of the vascularity on the heat conduction properties of the bone structure, three aspects can be distinguished (1) the influence of the microcirculation on the heat conduction properties of the bone material, (2) the influences of large blood vessels and (3) the heat transport at the bone surface in the highly vascularized periosteum As to the first effect, it can probably be assumed that the continuum model of the bone material still applies, but that λ_b should be adapted (Graf and Stein, 1957) The second effect will probably greatly disturb the heat flow, but is a quite local phenomenon that will be neglected here The third effect will be discussed in paragraph 5 4

With regard to long bones it has been shown (Rhinelander, 1972) that the greater part of the cortex thickness (> 2/3) is vascularized from within the medullar system and only the superficial part by the periosteal system In the diaphyseal region, the intramedullar vascularity is, at least temporarily, disturbed prior to fixation of endoprostheses and hence the greater part of the cortex will be without circulation until the periosteal system takes over the function of the intramedullar system (Rhinelander, 1972) It is therefore assumed as probable that the vascularity will exert no influence on the thermal conductivity in the diaphyseal cortex during the polymerization process

As regards the metaphyseal and epiphyseal regions of the bone, where the implant is fixated against spongeous bone, the function of the vascularity during surgery is uncertain, at least part of the circulation will be temporarily disturbed

Possible influences of the microcirculation can be evaluated by variation of λ_b guided by the results of Graf and Stein (1957), as shown in table 5 IV

5 3 4 *The cement bone interface*

It is a well known phenomenon that when heat flows across a contact region between two materials, the temperatures in the two materials at the contact surfaces are not equal the contact region has a certain heat flow resistance (e g Jacobs and Starr 1939, Fried, 1969) The heat resistance depends mainly on the roughness of the materials and the kind of intermediate medium (gas, liquid)

This contact heat resistance phenomenon can, in the simplest form, be described by

$$q = \beta \Delta T \qquad (5\ 10)$$

where q is the specific heat flow through the contact region (J/m²sec),
 ΔT the temperature drop over the interface (°C),
 β the interface conductivity (J/m²sec°C)

This mathematical model is illustrated in fig 5 4 Owing to the (in this case steady) heat flow (q) there is a certain temperature profile in materials 1 and 2 At the contact region or interface which is assumed to be infinitely thin, a discontinuity (ΔT) in the temperature profile is present, due to the heat flow resistance, the conductivity of the interface is described by β In reality, as illustrated in fig 5 4, the interface has a certain thickness (s_i) over which the temperature decreases more-or less continuously

The conductivity of the cement bone interface will depend on the structure and the preparation of the bony implant bed, the consistency of the cement and the pressure applied to it when inserted the presence of blood, water or bone debris and probably the dimensional behavior of the cement mass Owing to these random influences and the small dimensions

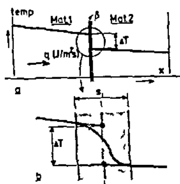


fig 5 4 Illustration of a simplified model of an interface heat resistance (a), showing the temperature profile in the two materials and the discontinuous temperature drop at the interface assumed as infinitely thin In reality (b) the interface has a certain thickness and the temperature drop is more-or less continuous

too the interface conductivity provided the linear model applies to this complicated structure will be very difficult to measure Hence the strategy will be to vary the interface conductivity β in a possible range in the analyses and to evaluate its influence on the heat conduction process

In order to obtain a rough impression of the value of β the steady state heat conduction in a plane model of an arbitrarily shaped bone cement interface was analysed using the methods described in chapter 4 The model is shown in fig 5 5 the interface is assumed to

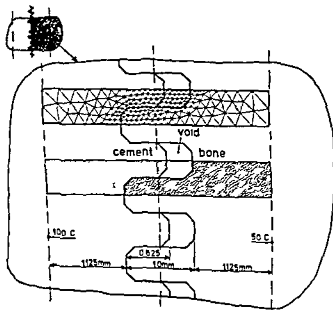


fig 5 5 A simplified plane model of an arbitrary cement-bone interface In the trabecular voids a nonconductive material is assumed, the element mesh for the simulation of the (steady state) heat conduction through the interface is shown

be 1 mm thick and consists of bone 'trabeculae', partly in contact with acrylic cement leaving intratrabecular gaps filled with a nonconductive medium For reasons of symmetry only a part of the model has to be regarded, the element mesh is shown in fig 5 5 (generated by computer, Schoofs *et al*, 1978) Parameter values were taken as $C_c = 1.8 \times 10^6$ J/m³°C, $C_b = 2.9 \times 10^6$ J/m³°C, $\lambda_c = 0.17$ J/msec°C, $\lambda_b = 0.4$ J/msec°C Fig 5 6 shows the temperature profile on two lines in the materials, as calculated in the computer simulation

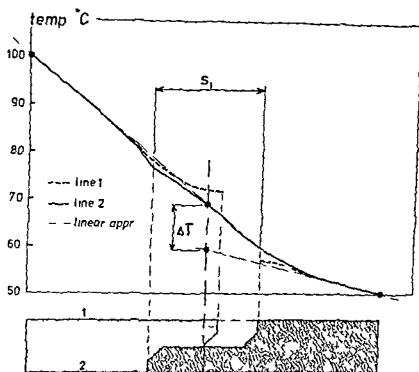


fig 5 6 Temperature profiles in the interface model on two lines as calculated in the FEM simulation and a linear approximation of these profiles in each material, which results in an apparent discontinuous temperature drop ΔT

Linear approximations of the temperature profiles were fitted to these graphs, resulting in a discontinuous temperature drop (ΔT) over an assumed infinitely thin 'interface' located *in the middle of the real interface In this simplified description the specific* heat flow can be calculated from

$$q = -\lambda_b \frac{dT_b}{dx} = -\lambda_c \frac{dT_c}{dx}$$

where $T_b(x)$ = temperature in bone (linear approximation)
$T_c(x)$ = temperature in cement (linear approximation)

The interface conductivity β can then be calculated from (5 10) which gives
$\beta = 375$ *J/m²sec°C in this case*
Isotherms as calculated with the FEM model are shown in fig 5 7 indicating that the tips of the trabeculae surrounded by cement will reach high temperatures even if the temperatures in the rest of the bone are not very high

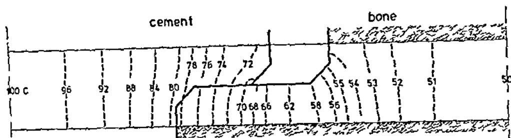


fig 5 7 Isotherms as calculated in the computer simulation indicating that the tips of trabeculae, surrounded by cement, may reach quite high temperature values

At the rather smooth cement implant interface the heat resistance will be low A value of β_{ci} = 1 000-10 000 J/m²sec°C should be appropriate (Fried 1969)

5 4 Boundary heat transport

Heat loss at the boundary of the model which will usually be the bone surface depends on a surface conduction and convection coefficient (α) as discussed in chapter 4 and on the ambient temperature (T_a)
When the bone surface is the boundary of the model the coefficient α depends on the heat exchange mechanism between the superficial bone and the periosteal circulation although no doubt conduction through the soft tissue also occurs Nothing appears to be known about these phenomena.
For technical surfaces in different media values for α were reported by Grober *et al* (1961) as shown in table 5 V

Medium (free convection)	α (J/m²sec°C)		Medium (forced convection)	α (J/m²sec°C)	
gas	3	24	gas	11	117
water	116	698	viscous liquids	58	582
bubbling water	1 163	23 260	water	581	10 630

table 5 V Values of α with respect to technological surfaces in different media (after Grober et al 1961)

Blood and soft tissues consist mainly of water and it has been shown that the thermal conductivity of soft tissues is only slightly less than water (water $\lambda \approx$ 0 6 J/msec°C (20 C) Eckert and Drake (1972) muscle $\lambda \approx$ 0 5 J/msec°C (21°C) Balasubramanian *et al* (1977)) In view of the values given in table 5 V it is then quite probable that $\alpha >$ 500 J/m²sec C and remotely possible that $100 < \alpha < 500$ J/m²sec°C The probability that there is an adequate heat transport at the bone surface was confirmed by d Hollander *et al* (1976) who measured a temperature increase of only 3 C at the outside surface of the femur during hip replacement the temperature dropped after reaching this peak value

5 5 Initial and ambient temperatures

The temperatures in the components of the bone prosthesis system, prior to insertion of the implant, depend on the circumstances Implants and bone cement will be approximately at 'room temperature' although both components may have been slightly warmed up by manual handling and the onset of the polymerization process The initial temperature of the bone (T_{0b}) is probably equal to the ambient temperature (T_a), which will not be higher than 37°C, but probably somewhat lower, for instance d Hollander *et al* (1976) have measured values between 32 and 35°C (see paragraph 2 1)

5 6 Conclusions

Based on a thorough review of the relevant literature, estimates for the thermal properties of bone prosthesis systems have been discussed in this chapter
The geometry of the system has not been discussed, as it depends so much on the joint component which is under consideration and can better be treated in the chapters concerned
A summary of probable and possible values is shown in table 5 VI It should be borne in mind that in some cases the values and value ranges shown are only educated guesses, especially where the 'possible range' is concerned Sometimes (as for example for λ_c) only one value is shown in the 'probable value or range' column simple because only one value has been published, the 'possible range' column then reflects uncertainty about this value The ranges in these columns will be used later as lower and upper boundaries in the parametric analyses Some parameters are adjustable, for instance ν_m (by the P/L ratio) and C_c (by additives), the probable ranges of adjustability are then shown in the relevant column

As can be concluded from table 5 VI many properties might well come in for more thorough experimental investigations For such investigations it is of importance to know how sensitive the process of heat generation and conduction is for the parameter values, so as to establish which parameters are the most important and the accuracy with which each parameter would have to be measured Analyses such as those presented in the following chapters, where the influences of the parameters on the process are evaluated, can provide guidelines for such experiments

parameter	unit	probable value	adjustable range	possible range
Heat generation				
ρ_m	kg/m³	0 94x10³	–	–
Q_t	J/kg	5 4x10⁵	–	–
ν_m	–	0 35	0 27 0 42	–
Q	J/m³	1 8x10⁸	1 4 2 1x10⁸	–
p(t)	–	$p_1(t)$	$p_2(t)$ $p_3(t)$	–
t_r	sec	150	–	–
τ	sec	200 400	–	–
Heat capacity and conductivity				
Acrylic cement				
C_c	J/m³°C	1 8 2 0x10⁶	–	1 7 2 1x10⁶
λ_c	J/msec°C	0 17	–	0 14 0 20
Cortical bone				
C_b	J/m³°C	2 2 3 2x10⁶	–	1 8 4 1x10⁶
λ_b	J/msec°C	0 3 0 5	–	0 2 0 6
Spongeous bone				
C_b	J/m³°C	2 8 3 4x10⁶	–	2 6 3 6x10⁶
λ_b	J/msec C	0 5	–	0 4 0 6
Interface conductivity				
β_{ci}	J/m²sec°C	1 000 10 000	–	500 ∞
β_{cb}	J/m² sec C	100 1 000	–	50 ∞
Bone surface heat loss				
α	J/m²sec°C	500 10 000	–	100 ∞
Initial and ambient temperatures				
$T_a = T_{0b}$	°C	32 35	–	30 37
T_{0c}	°C	20 25	–	–
T_{0i}	°C	20 25	–	–

table 5 VI Probable and possible values of the relevant thermal parameters Implant property values were shown in table 5 II

CHAPTER SIX

EVALUATION OF THE MODEL

In order to evaluate the model as to its suitability for the curing cement and judge the para meter value estimates, two experiments published in the literature were simulated As not all the parameters that have to be given a value in the model calculations were measured in the experiments and the reliability of the experimental results is sometimes doubtful, this simu lation process cannot be regarded as a true verification procedure, but merely as a rough evaluation

6 1 A ball of curing acrylic cement

Ohnsorge and Kroesen (1969) measured temperatures as a function of time in the centre and at the surface of a ball of acrylic cement curing in free air Parameter values that can be derived from their publication are given in table 6 I

commercial brand	Palacos	initial temperature	T_{0c} = 25°C
P/L ratio	2 1 gr/cc	ball radius	R = 2 2x10^{-2} m
ambient temperature	T_a = 25°C	ball mass	m_c = 52 2x10^{-3} kg

table 6 I Data from Ohnsorge and Kroesen (1969)

The monomer fraction in the mixture can be evaluated using fig 5 1 and the given P/L ratio from which it follows that $v_m \approx 0\ 34$ Hence, using the data presented in paragraph 5 2, $Q \approx 1\ 7\text{x}10^8$ J/m^3 For cooling in free air $\alpha \approx 3$ 24 J/m^{2}sec°C (table 5 V)
Owing to symmetry of the ball only a section has to be taken into account in the analysis Fig 6 1 shows the element mesh for the axisymmetric model At the boundaries r = 0 and z = 0, α is taken as zero to simulate the spherical geometry Of course a spherical model would be more appropriate here from a theoretical point of view, however, the computer program is only suited for plane and cylindrical models
The time step Δt in the solution procedure was taken as 10 sec 100 steps were taken into account The polymerization function $p_1(t)$ was used with t_r = 0 and τ = 240 sec (a value that will be motivated at the end of this paragraph)
Fig 6 2 shows an example of calculated results the temperature in the ball as a function of r for three different values of α at time t = 350 sec It is found even for rather high values of α that the heat flow from the centre (which is proportional to $\frac{dT}{dr}$) is practically zero Hence the process in the centre is practically adiabatic Since in that case (near the centre)

$$C_c \frac{dT}{dt} = Q \frac{dp}{dt} \quad \text{hence} \quad T(t) = \frac{Q}{C_c} p + T_{0c}$$

it follows that

fig 6 1 Element me.h for the computer simulation of the heat generation and conduction process in a curing ball of acrylic cement, the model is axisymmetric The para meters on which the process of heat generation and conduction depend are also shown

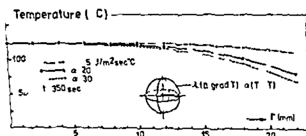


fig 6 2 The temperature in the cement ball as a function of the radius r at time t = 350 sec, as calculated for three different values of α

CHAPTER SIX

EVALUATION OF THE MODEL

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it follows that

6.2. Acrylic cement curing in a Teflon cup

Meyer *et al* (1973) measured temperatures as a function of time at eight locations in acrylic cement curing in a Teflon cup The cup (and the cement slice) were axisymmetric Initial temperatures height of the cement slice and P/L ratio were varied The cup is shown together with the element mesh for the simulation in fig 6 4 Only the experiments entailing a cement slice height of 10 mm were simulated Measuring points were numbered 1 3 5 and 7 (in the middle of the cement slice) and 2 4 6 and 8 (near to the Teflon) all located in an axial section

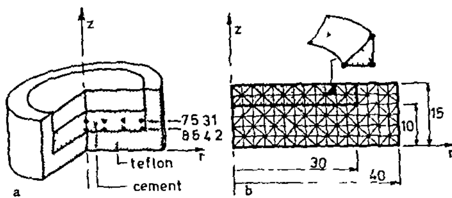


fig 6 4 (a) The Teflon cup with the cement mass as used for experiments by Meyer et al (1973) temperature measuring points are shown 7 and 8 on the symmetry axis 7 5 3 and 1 in the middle of the mass 8 6 4 and 2 near the Teflon (b) Dimensions and element mesh for the computer simulation

commercial brand	Simplex p
P/L ratio	1 5 2 2 5 and 3 gr/cc (ν_m 0 42 0 35 0 30 and 0 27 fig 5 1)
initial temperature	4 15 20 30 and 37°C
ambient temperature	equal to initial temperature
retardation time	$t_r \approx 150$ sec

table 6 II Data supplied by Meyer et al (1973)

Table 6 II shows some values for parameters that can be derived from the publications of Meyer *et al* Parameter values for Teflon were taken in accordance with table 5 II The polymerization time was chosen in such a way that the time at which the center point temperature (point 7) reached its peak coincided in simulation and experiment (τ = 350 sec for P/L = 2 gr/cc and $T_a = T_{0c}$ = 25°C) the polymerization curve $p_1(t)$ was again used In the solution procedure the time step (Δt) was chosen as 10 sec 100 steps were taken into account a time step of 1 sec with 1000 steps did not give significantly different results (Huiskes 1977) Values for cement parameters were taken in accordance with those mentioned in paragraph 5 6 except for C_c By taking C_c = 1 75x10^6 J/m^3°C a good agreement resulted for the measured and calculated maximal center point temperatures which is the same value for C_c as evolved from the previous simulation

- the temperature in the centre is proportional to the polymerization function, which gives the option of evaluating this function by measuring the temperature in a comparable experimental set up,
- when the maximal temperature in the centre is denoted by T_c, then

$$T_c - T_{0c} = \frac{Q}{C_c}$$

thus the value of $\frac{Q}{C_c}$ can be evaluated directly from the experiment

For the experiment it was reported that $T_c = 122°C$, hence $\frac{Q}{C_c} = 97°C$

Assuming $Q = 1.7 \times 10^8\ J/m^3$, it follows that $C_c = 1.75 \times 10^6\ J/m^3 °C$, which is somewhat lower than estimated in chapter 5, but quite realistic The difference could easily be explained by experimental inaccuracies, incomplete polymerization or a slightly different P/L ratio

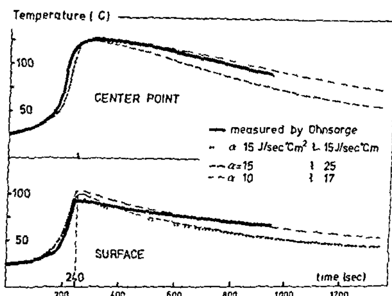


fig 6 3 Temperatures as a function of time in the centre and at the surface of the ball, as measured and as calculated using different values for α and λ

Fig 6 3 shows the centre and surface temperatures as a function of time as calculated for different values of λ and α, compared to the experimental results Obviously the value of λ exerts more influence on the centre temperature while α exerts more influence on the surface temperature The curve for $\lambda = 0.17\ J/msec°C$ and $\alpha = 10\ J/m^2sec°C$ shows the best agreement with the experimental curves
The polymerization time τ was chosen in such a way that the time at which the surface temperature reached its peak in the model coincided with the experimental finding
It is remarkable that in using the polymerization function $p_1(t)$ both experimental curves are approximated reasonably well This gives confidence in the applicability of the general shape of this polymerization function
In the experiment the surface temperature was slightly higher than in the simulation This is probably caused by monomer evaporation at the surface

It should be remarked that due to the steep temperature gradient the temperature measure ments at the interface are somewhat unreliable Moreover the exact position of the interface thermocouples is not mentioned in the publication

Fig. 6 6 shows a comparison of temperatures as a function of time as measured and as calculated where $\beta = 50\ J/m^2 sec^\circ C$ at four of the measuring points Since the location of measuring points 1 2 and 8 is not exactly known calculated results for points in the neigh borhood are shown in the graphs Results of measuring points 3 and 5 were practically equal to those of point 7 and those of points 4 and 6 were practically equal to those of point 8

Again the use of the polymerization function $p_1(t)$ results in quite reasonable approxima tions of the experimental curves except for a small shift in the polymerization time at the cooler points

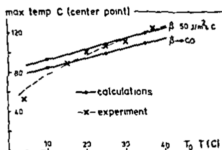


fig 6 7 Maximal cement temperature as a function of the initial temperatures as measured by Meyer et al (1973) and as calculated in the model

Fig. 6 7 shows the influence of the initial temperature on the maximal temperature value at the center point as calculated and as measured Evidently a reliable prediction results from the model so long as the range of variation is not too extended In the experiment an increase in the polymerization time results for low values of T_{0c} not taken into account in the model

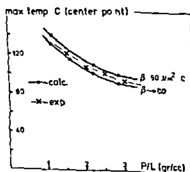


fig 6 8 The maximal cement temperature as a function of the P/L ratio as measured by Meyer et al (1973) and as calculated in the model

Fig. 6.8 shows the influence of the P/L ratio on the maximal temperature value at the center point as calculated and as measured Again it is apparently possible using the model to predict this influence with quite good accuracy

It was established that a variation of α in the range from zero to infinite exerted no significant influence on the maximal cement temperatures Likewise a variation of the Teflon properties within a realistic range, and a variation of λ_c within a realistic range exerted little influence
To be able to obtain a reasonable approximation of the temperatures in all measured points the conductivity at the cement Teflon interface had to be taken as $\beta = 50$ J/m²sec°C

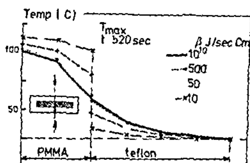


fig 6 5 Temperatures as a function of the axial coordinate (z) in the cement and in the Teflon, at time t = 520 sec, as calculated for different values of the interface conductivity β

Fig 6 5 shows the influence of β on the temperature profiles in cement and Teflon along the axis of the structure The fact that such a rather low value of β has to be assumed to approximate the temperature values measured close to the cement Teflon interface, is probably caused by steep temperature gradients in reality near the interface which cannot be simulated due to the coarseness of the element mesh

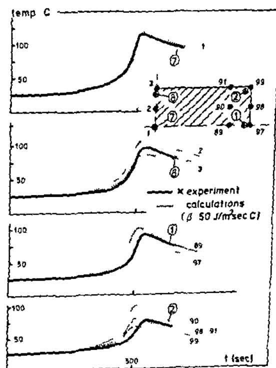


fig 6 6 Temperatures as a function of time as measured at 4 points in the cement mass by Meyer et al (1973), and as calculated at different points close to the measuring points indicated in the figure

It should be remarked that due to the steep temperature gradient the temperature measurements at the interface are somewhat unreliable Moreover the exact position of the interface thermocouples is not mentioned in the publication
Fig. 6 6 shows a comparison of temperatures as a function of time as measured and as calculated where $\beta = 50\ J/m^2 sec°C$ at four of the measuring points Since the location of measuring points 1 2 and 8 is not exactly known calculated re ults for points in the neighborhood are shown in the graphs Results of measuring points 3 and 5 were practically equal to those of point 7 and those of points 4 and 6 were practically equal to those of point 8
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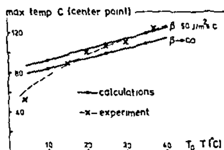


fig 6 7 Maximal cement temperature as a function of the initial temperatures as measured by Meyer et al (1973) and as calculated in the model

Fig 6 7 shows the influence of the initial temperature on the maximal temperature value at the center point as calculated and as measured Evidently a reliable prediction results from the model so long as the range of variation is not too extended In the experiment an increase in the polymerization time results for low values of T_{0c} not taken into account in the model

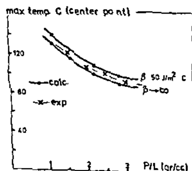


fig 6 8 The maximal cement temperature as a function of the P/L ratio as measured by Meyer et al (1973) and as calculated in the model

Fig. 6 8 shows the influence of the P/L ratio on the maximal temperature value at the center point as calculated and as measured Again it is apparently possible using the model to predict this influence with quite good accuracy

6.3 Conclusions

By simulation of two experiments presented in the literature it was shown that the process of heat generation and conduction in curing acrylic cement can be simulated with acceptable accuracy and that the estimates for (cement) parameter values discussed in chapter 5 are quite reasonable. The general shape of the measured polymerization function is found to be realistic. Although the polymerization function is not independent of the temperature, it is found that in reality its influence only results in a relatively small shift of the curves, especially in the initial part of the polymerization process. The value of β exerts a considerable influence on temperature values near the interface of the cement and the adjoining material. *In the bone prosthesis system this is precisely the location where the temperature* values are of interest. As has been discussed previously, results of temperature measurements in this region are unreliable. But due to the fact that so little is known about the value of β, the same is true for calculated temperature values in this region. By conducting parametric analyses, however, a good impression can be obtained on the possible temperature values and the influences of the important parameters on these values. In this respect the model gives much more information than experiments possibly could.

CHAPTER SEVEN

PARAMETRIC ANALYSES WITH RESPECT TO INTRAMEDULLARY FIXATED IMPLANTS

7 1 Description of the model

In this chapter the influences of the relevant parameters on the process of heat generation and conduction in a realistic system will be evaluated by means of parametric analyses In order to maintain insight into the effect of parametric changes the system to be analysed should be as simple as possible Therefore a both simple and realistic model was chosen

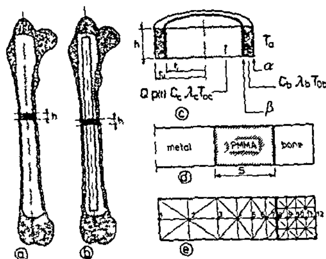


fig 7 1 An arbitrary long bone filled with acrylic cement (a), which may also contain an implant (stem) (b) The axisymmetric model of the diaphysis region is shown (c) giving the parameters that influence the heat generation and conduction process also The dimension of the implant may vary (d) the cemen layer thickness is denoted by s The element mesh used in the computer simulation is also shown (e)

The model consists of a slice from the diaphysis of an arbitrary long bone (fig 7 1) the medullary canal of which is filled with curing acrylic cement (fig 7 1 a) and may also contain a metal stem (fig. 7 1 b) The cortex of the bone is assumed to be axisymmetric and heat flow in the axial direction is assumed to be zero The model and the model parameters in the event that no stem is present are shown in fig 7 1 c When a stem is present the cement layer thickness is denoted by s (mm) (fig 7 1 d) The element mesh for the model is shown in fig 7 1 e mesh refinement is applied close to the cement bone interface so as to be able to describe a steep temperature gradient in this region adequately

The parameters were varied with respect to a reference value The set of reference values is shown in table 7 1 In the reference case no implant is present as it will no doubt be the

parameter	unit	reference value	parameter	unit	reference value
Geometry (no implant present)			Cement		
r_u	m	16×10^{3}	C_c	$J/m^3 {}^\circ C$	$1\ 75 \times 10^6$
r_i	m	12×10^{3}	λ_c	$J/msec^\circ C$	0 17
s (1)	m	12×10^{3}	T_{0c}	$^\circ C$	20
Heat-generation			Bone (cortical)		
Q	J/m^3	$1\ 7 \times 10^8$	C_b	$J/m^3 {}^\circ C$	$2\ 9 \times 10^6$
p(t)	–	$p_1(t)$	λ_b	$J/msec^\circ C$	0 4
t_r	sec	0	T_{0b}	$^\circ C$	37
τ	sec	350			
Cement bone interface			Bone surface		
β_{cb}	$J/m^2 sec^\circ C$	1,000	α	$J/m^2 sec^\circ C$	500
			T_a	$^\circ C$	37

table 7 1 Reference values for parameters in the diaphysis model, (1) In the reference case no implant is present, hence $s = r_i$

'worst case for the bone temperature values The reference values were chosen as more or less probable average values, as summarized in table 5 VI, if there were serious uncertainty about a parameter (as for instance in the case of β), a more or less 'worst case' value was chosen In table 5 VI $Q = 1\ 8 \times 10^8\ J/m^3$ and $C_c = 1\ 9 \times 10^6\ J/m^3 {}^\circ C$ were given as probable values Based on the results of the simulations described in the previous chapter $Q = 1\ 7 \times 10^8\ J/m^3$ and $C_c = 1\ 75 \times 10^6\ J/m^3 {}^\circ C$ have been chosen as probable values in the forthcoming analyses

For the calculations where a (metal) implant is assumed to be present, values for the para meters are taken in accordance with table 5 II (Cr Ni steel, $C_i = 3\ 6 \times 10^6\ J/m^3 {}^\circ C$, $\lambda_i = 14\ J/msec^\circ C$)

Parameters will be varied in what is expected to be a realistic range, which is determined either by uncertainty about the parameter value (see table 5 VI), or by a range in which the parameter may vary in reality due to circumstances or cement composition Since the solu tion procedure is numerical, the parametric analysis is carried out by calculating for each parameter separately the temperatures for several values and interpolating between separate results In some calculations, values different than those shown in table 7 1 were taken for other than the varied parameter where this is the case, the deviating value will be mentioned

Fig. 7 2 a shows temperatures as a function of time in the cement and the bone and fig 7 2 b temperatures as a function of the radius r at three different times The middle of the cement mass (point 1) reaches approximately 121°C (T_c), the bone at the bone cement interface approximately 59°C (T_b)

In order to judge the possibilities of thermal damage of the bone tissue the temperature values in the bone have to be taken into account, but also the exposure time These data have to be compared to the threshold levels shown in fig 3 1

To simplify this procedure the penetration depths of the 50°C and 55°C isotherms into the bone as function of time ($\delta(t)$) were calculated (fig 7 3) The maximal penetration depth of the 50°C isotherm is denoted as δ_m

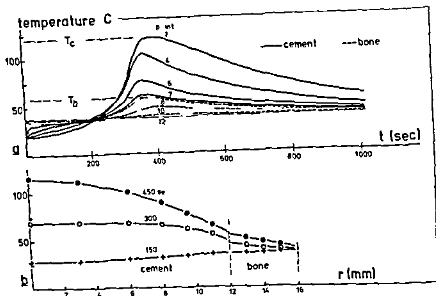


fig 7 2 (a) Temperatures as a function of time at the 12 points indicated in fig 7 1 e T_c and T_b are the maximal temperatures in cement and bone respectively (b) Temperatures as a function of the radius r at three different times (both calculations of the reference case)

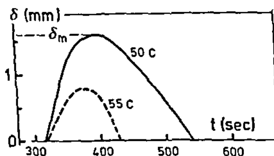


fig 7 3 The penetration depths of the 50°C and the 55°C isotherms into the bone cortex as functions of time δ_m is the maximal penetration depth of the 50 C isotherm

If this graph is compared to fig 3 1 it is found that about 0 5 mm of the bone would be liable to bone cell necrosis and about 1 mm to vascular damage

To evaluate the influences of parametric change three variables that are representative of the temperature distribution will be regarded the maximal cement temperature (T_c as shown in fig. 7 2 a or ΔT_c, defined as T_c -20 C) the maximal bone temperature at the interface (T_b (fig 7 2.a) or ΔT_b defined as T_b -37 C) and the maximal penetration depth of the 50 C isotherm (δ_m fig 7 3)

7 2 Heat transport at the bone surface

The heat loss at the outside surface of the bone depends on α ($J/m^2 sec°C$) and T_a (°C) Theoretically speaking, α may vary between zero (bone surface temperature equal to T_a) and infinite (bone completely isolated) Temperatures at the cement and bone points as a function of time for both these upper and lower boundary values are shown in fig 7 4 In the event of complete isolation, the whole system warms up to around 73°C, a value that can easily be verified using data for total heat generation and heat capacity properties

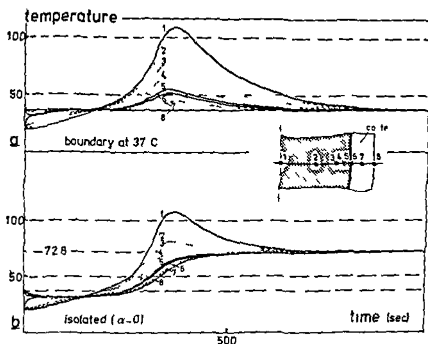


fig 7 4 Temperatures as a function of time at 8 points in the cement and the bone as calculated in the event of an idealized heat transport (a) and of an idealized isolation at the bone surface (b)

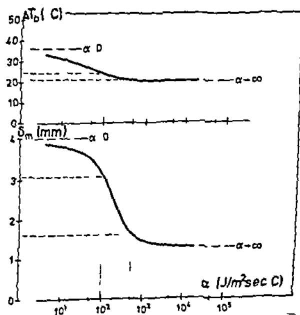


fig 7 5 The influence of α on the maximal bone temperature increase ΔT_b and on the maximal penetration depth of the 50°C isotherm δ_m (logarithmic scale for α)

As follows from fig 7 4 the value of α has no significant influence on T_c The influence of α on ΔT_b is shown in fig 7 5 It is found that α has little influence when $\alpha > 100$ The influence of α on δ_m too is shown in fig 7 5 for α to have little influence in this case it would have to be over 500 for $\alpha < 500$ the influence is pronounced

7 3 Cement-bone interface conductivity

The influence of β (J/m² sec°C) on ΔT_b and δ_m is shown in fig 7 6 β has a marked influence for $\beta < 1000$ A value of 1000 as used in the reference case or higher more-or less simulates worst case conditions for the bone

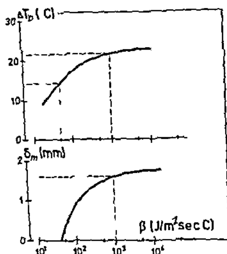


fig 7 6 The influence of β on ΔT_b and on δ_m (logarithmic scale for β)

7 4 Bone and implant dimensions

When a metal implant is present in the cement it functions as a heat sink, due to its superior heat capacity and conductivity properties An example of temperature values as calculated assuming an axisymmetric stem of 12 mm thickness in the cement is shown in fig 7 7 Values taken for the parameters in this case were equal to those in the reference case with the exceptions $\beta_{cb} = 500$ J/m² sec°C and $T_{0c} = T_{0i} = 25°C$ β_{ci} was taken as infinite As follows from fig 7 7 T_c reaches only approximately 80°C and T_b reaches approximately 54°C The maximal penetration depth of the 50°C isotherm $\delta_m \approx 1$ 3 mm (fig. 7 7 c) The bone at the cement bone interface is maintained at a temperature of more than 50°C for only 110 sec which according to the threshold curve in fig 3 1, is not enough to cause vascular damage or bone cell necrosis As can be concluded from the tem perature as a function of time in the stem (fig. 7 7 a), the stem takes up the heat initially and later returns it to the rest of the system In a real prosthesis stem heat will also flow in the axial direction which will reduce the temperatures even further

7 2 Heat transport at the bone surface

The heat loss at the outside surface of the bone depends on α (J/m² sec°C) and T_a (°C) Theoretically speaking, α may vary between zero (bone surface temperature equal to T_a) and infinite (bone completely isolated) Temperatures at the cement and bone points as a function of time for both these upper and lower boundary values are shown in fig 7 4
In the event of complete isolation, the whole system warms up to around 73°C, a value that can easily be verified using data for total heat generation and heat capacity properties

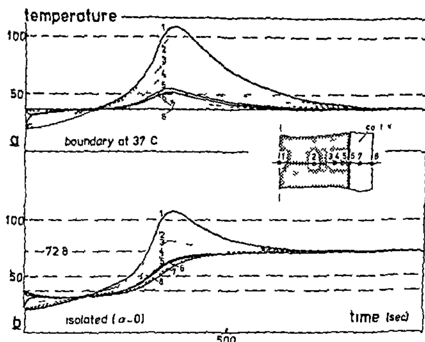


fig 7 4 Temperatures as a function of time at 8 points in the cement and the bone as calculated in the event of an idealized heat transport (a) and of an idealized isolation at the bone surface (b)

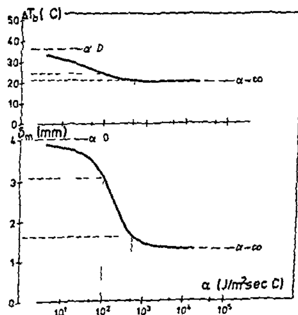
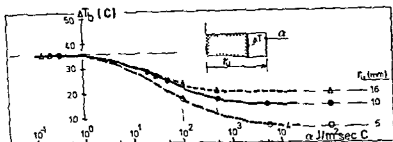


fig 7 5 The influence of α on the maximal bone temperature increase ΔT_b and on the maximal penetration depth of the 50°C isotherm δ_m (logarithmic scale for α)

	r_i (mm)	r_u (mm)	simulated bone
on	12	16	human femur
iation 1	7 5	10	dog femur
ariation 2	3 75	5	rabbit femur

7 II *Variations in bone dimension*



g 7 8 *The influence of α on ΔT_b for three different bone dimensions (logarithmic scale for α)*

α ≈ 100 the difference between the dog bone and the human bone will have practically anished and for α ≈ 10 the difference between the rabbit bone and the human bone As previously probably α > 500 hence results of animal experiments in this respect simply be translated into human circumstances

/hen animals have to be used as models in this respect a method of scaling could be intro When the differential equation that describes the process of heat generation and ı (chapter 4) is written in dimensionless form it follows that if the dimensionless mbers

$\frac{\lambda_c}{r_i^2}$ and $\frac{\tau\lambda_b}{C_b(r_u-r_i)^2}$ (Fourier number)

$\frac{\beta(r_u-r_i)}{\lambda_b}$ and $\frac{\alpha(r_u-r_i)}{\lambda_b}$ (Biot number)

$\frac{Q}{T_a}$ and r_u/r_i

equal in the human and the animal model the results will be equal in both cases For the ourier numbers this could be accomplished by adapting the polymerization time (τ) and heat capacity of the cement (C_c) in the animal case then also Q would have to be for the source number (Q/C_cT_a)

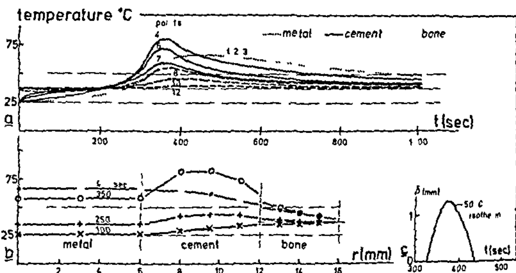


fig 7 7 (a) Temperatures as a function of time in implant, cement and bone, at 12 points (indicated in fig 7 1 e), (b) temperatures as function of the radius r in the three materials at three different times, (c) penetration depth of the 50°C isotherm into the bone cortex as function of time

By varying the bone dimensions, the influence of individual differences can be evaluated, and the possibilities can be judged of using animal models in experimental heat conduction studies in vivo

In first order approximation, the relation between heat generation and heat conduction in a system can be estimated by comparing the heat producing volume to the heat transporting surface In the medullary canal assuming axisymmetry, the ratio between these two para meters (volume/surface) is proportional to the inner bone radius r_i Hence it should be expected that the temperature values measured in bones of small animals are not represen tative of humans, as r_i greatly differs in the various animals This follows also from regarding the steady state heat conduction resistance of the cortex and the bone surface (R_c(msec°C/J)) which is found from (e g Eckert and Drake, 1972)

$$R_c = \frac{\ln(r_u/r_i)}{\lambda_b} + \frac{1}{\alpha r_u} \qquad (7\ 1)$$

From (7 1) it follows that α exerts its greatest influence on the smaller bone When $\alpha \to \infty$, R_c depends on $\ln(r_u/r_i)/\lambda_b$ only and if r_u/r_i and λ_b were constant in different animals deviations in the bone temperatures would be due to differences in the heat generation conduction relation only When $\alpha = 0$, the heat resistance is infinite and in this case the end temperature of the system depends on the total heat generation in the cement and the heat capacity of the cement and the bone hence on the ratio volume cement/volume cement and bone in the event that r_u/r_i is constant in different animals this ratio and hence the maximal temperature, is equal

To investigate the differences further the model was analyzed for different dimensions (see table 7 II), in all three cases $r_u/r_i = 1\ 33$ was assumed
Fig 7 8 shows the influence of α on the maximal bone temperature increase ΔT_b for the three different dimensions As was previously predicted, for low α and for high values of α it has no influence on the differences in ΔT_b, while for low values there is no difference

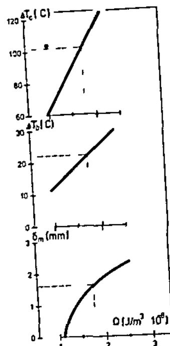


fig 7 10 The influence of Q on ΔT_c ΔT_b and δ_m

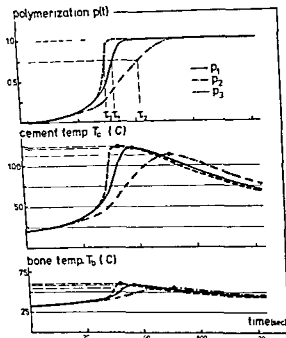


fig 7 11 From top downwards the three polymerization functions applied ($p_1(t)$ $p_2(t)$ $p_3(t)$) the cement temperature (center point) and the bone temperature (interface) that result from these functions

Little can be done to satisfy the requirements for the Biot numbers, so scaling would only be possible if $\alpha \to \infty$ and $\beta \to \infty$

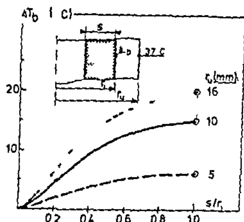


fig 7 9 Maximal bone temperature increase (ΔT_b) as a function of the relative cement layer thickness (s/r_i), for three different bone dimensions (r_u/r_i constant)

Fig 7 9 shows the maximal temperature increase of the bone (ΔT_b) in the event that an implant is present as a function of the ratio between the thickness of the cement layer and the inner radius of the bone (s/r_i), for the three bone dimensions In the calculations on which these results are based, α was taken as infinite For $s/r_i = 1$, no implant is present in the cement and the medullary canal is completely filled with acrylic cement As follows from these graphs, besides the bone dimension the thickness of the cement layer (the thickness of the implant) has a marked influence on the maximal bone temperature

As to influences of individual differences in bone dimension these can also be estimated using formula (7 1) When the differences are such that r_u/r_i remains constant the previously discussed influences apply in the same way
When the cortex thickness varies assuming equal r_i, only the heat conduction properties change It can be calculated from formula (7 1) that, with respect to the (human) reference case ($\alpha = 500$ J/m²sec°C), a variation in cortex thickness from 3 to 5 mm has the same influence as a variation in α from about 3250 to 222 J/m²sec°C a variation that hardly affects ΔT_b but has a significant influence on δ_m (fig 7 5)

7 5 Heat generation parameters

The heat generation in the cement depends on Q and on p(t) The influence of Q on ΔT_c, ΔT_b and δ_m is shown in fig 7 10 Q has a marked influence on all temperature values

Apart from the polymerization function $p_1(t)$ two other curves were applied, $p_2(t)$ a slower curve and $p_3(t)$ a faster curve, respectively (fig 7 11) These curves were different especially in their auto acceleration aspect, the best way to characterize these differences is by their maximal polymerization rate ($\theta_p = \max(dp/dt)$) rather then by their polymerization time ($\theta_{p1} = 11 \times 10^{-3} sec^{-1}$, $\theta_{p2} = 4\,4 \times 10^{-3} sec^{-1}$ $\theta_{p3} = 28 \times 10^{-3} sec^{-1}$) The resulting cement and bone temperatures as a function of time for these three curves are shown in fig 7 11

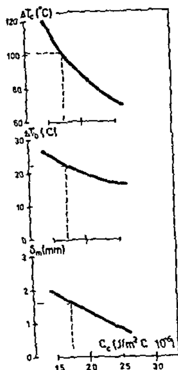


fig 7 13 The influence of C_c on ΔT_c ΔT_b and δ_m

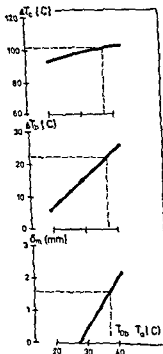


fig 7 14 The influence of $T_{ob} = T_a$ on ΔT_c ΔT_b and δ_m

The results for curve $p_3(t)$ are practically equal to those of an idealized 'snap curing' cement which is as fast as possible Application of curve $p_2(t)$ gives a reduction of about 4°C in the maximal interface bone temperature T_b as compared to curve $p_1(t)$, and a reduction of about 0 5 mm in δ_m Between the results of curves $p_1(t)$ and $p_3(t)$ there is only a slight difference

7 6 Heat capacity and conductivity parameters

The influence of the heat capacity of the bone is but slight over a wide range For $2 \times 10^6 \leq C_b \leq 4 \times 10^6$ J/m³°C, the influence on T_c is insignificant, T_b varies between 60°C and 57°C and δ_m varies between 1 8 mm and 1 3 mm

The conductivity of the bone, λ_b, has a greater influence on both T_b and δ_m especially for low values Fig 7 12 shows the influence on ΔT_b, for $0\,2 \leq \lambda_b \leq 2\,0$ J/msec°C and different values for α It should be remarked that such a wide range for λ_b is not realistic

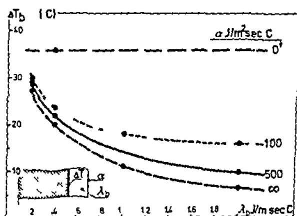


fig 7 12 The maximal bone temperature increase (ΔT_b) as a function of λ_b, for different values of α.

The value of λ_c has no significant influence on T_c For $0\,14 \leq \lambda_c \leq 0\,20$ J/msec°C, which is a rather wide range T_b varies between 57°C and 60°C, and δ_m varies between 1 3 mm and 1 7 mm
The heat capacity of the cement, C_c, has a marked influence on T_c, T_b and δ_m in a range of $1\,5 \times 10^6 \leq C_c \leq 2\,5 \times 10^6$ J/m³°C, as is shown in fig 7 13 C_c is one of the parameters that can be adjusted by adding material of a higher heat capacity to the cement, as will be discussed in chapter 9

7 7 Initial and ambient temperatures

The influence of the cement initial temperature on T_c, T_b and δ_m in a range of $15 \leq T_{0c} \leq 25$°C is quite insignificant A greater range is not realistic at least not in the model because the initial temperature will probably significantly affect the polymerization process, an influence that is not taken into account in the model

parameter	% increase T_c / % increase par	% increase T_b / % increase par	% increase δ_m / % increase par
r_i (1)	–	0 15	–
Q	0 74	0 37	1 43
λ_b	- 0 02	- 0 12	- 0 37
C_b	- 0 02	- 0 07	- 0 45
λ_c	- 0 06	0 06	0 32
C_c	- 0 55	- 0 21	- 1 20
T_{0c}	0 08	0 04	0 19
$T_{0b} = T_a$	0 12	0 56	3 70

table 7 III Sensitivity factors of T_c T_b and δ_m for changes in the parameters The numbers give the percentage increase per percentage increase of the parameters (1) It is assumed that r_u changes accordingly relative to r_i In this case the influences on T_c and δ_m were not calculated

parameter	unit	probable value or range	possible range
r_i	mm	11 13	12 14
α	$J/m^2 sec°C$	500 10 000	100 ∞
β	$J/m^2 sec$ C	100 1 000	50 ∞
Q	J/m^3	$1 7\times10^6$	1 65 $1 75\times10^6$
p(t)	–	p_1	p_2 p_3
λ_b	J/msec C	0 3 0 5	0 2 0 6
C_b	J/m^3 C	2 2 $3 2\times10^6$	1 8 $4 1\times10^6$
λ_c	J/msec°C	0 17	0 16 0 18
C_c	$J/m^3°C$	$1 75\times10^6$	1 7 $1 8\times10^6$
T_{0c}	°C	20	18 25
T_a	C	32 25	30 37

table 7 IV Estimated ranges of the parameter values

based on the literature review (discussed in chapter 5) the experiment simulations (discussed in chapter 6) and in some cases on an educated guess The diagram in fig 7 15 shows the approximative factors by which ΔT_b and δ_m will deviate from their reference values for parameter values within their ranges. If it is assumed that the influences of all parameters are independent a first order approximation of the probable ranges in ΔT_b and δ_m can be calculated by multiplication of separate influences (for example if f_1 and f_2 are upper or lower boundary factors of two parameters in fig 7 15 the combined influence factor would in first order approximation

Both T_b and δ_m are greatly influenced by the initial bone temperature T_{0b} and the ambient (periosteal blood) temperature T_a, as shown in fig 7 14 T_{0b} and T_a are taken as equal, because both represent the local temperature of the biological system

The *implant initial temperature, in the event that an implant is present,* was not varied As follows from a first order approximative consideration of the 'heat sink' capacity of the implant, reducing the initial temperature by 10°C will have about the same influence as increasing the stem radius by 1 mm (for a radius of approximately 6 mm)

7 8 Conclusions

The influence of α *(J/m²sec°C) on the temperature values is slight if* $\alpha > 500$ *If* $\alpha < 500$ however, the influence especially on δ_m is quite pronounced, a lower value of α would then make a greater part of the cortex liable to necrosis As discussed in paragraph 5 4 it is quite probable that $\alpha > 500$
The influence of the *interface conductivity is pronounced if* $\beta < 1000$ *J/m²sec°C* This might well be so and in that case the temperatures in the bone may be much lower although it should be borne in mind that in single trabeculae surrounded by cement the bone may still reach high maximal temperature values, as discussed in paragraph 5 3 4
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Also the presence of a metal stem in the cement (as, for instance in intramedullary fixated implants) has a marked effect on the temperatures The influence of the stem thickness is great, owing to a combined effect of a greater heat sink capacity of the implant and a lesser cement layer thickness

The influences of the other parameters on T_c, T_b and δ_m can be linearized in the neighbourhood (usually over a fairly wide range) of their reference values
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It is remarkable that Q, C_c and $T_{0b} = T_a$ exert the greatest influences These parameters belong to the ones that can be influenced by the surgeon or the cement manufacturer as will be discussed in chapter 9

It was shown in the reference calculation that the bone reached a maximal temperature of approximately 59°C while the inner cortex up to 1 6 mm from the interface reached temperature of 50°C and over Where there was a (metal) implant of 12 mm in thickness the bone reached a maximal temperature of 54°C while 1 3 mm of the inner cortex reached a *temperature of* 50°C or over As these temperatures were maintained for only a short time, the cortex tissue in the latter case would not be liable to tissue necrosis applying the threshold curve of fig 3 1
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p(t)	–	p_1	p_2 p_3
λ_b	J/msec C	0 3 0 5	0 2 0 6
C_b	J/m³°C	2 2 3 2x10⁶	1 8 4 1x10⁶
λ_c	J/msec°C	0 17	0 16 0 18
C_c	J/m³°C	1 75x10⁸	1 7 1 8x10⁸
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cortex in a very small zone near the interface is just possible If the influence of the initial bone temperature probably less than 37°C is taken into account necrosis would be im probable Also it can be concluded that in the case of the rabbit femur where the whole medullar canal is filled with acrylic cement tissue necrosis is quite improbable One should be cautious with such conclusions in an analysis of this kind that is in essence meant to evaluate influences and tendencies rather than to find absolute data However it appears very unlikely that the bone tissue necrosis found by Feith (1975) in his rabbit experiments would be principally caused by the heat of polymerizing as will be further discussed in paragraph 7 9

At this point it should be remarked that although the thermal damage threshold curves in fig 3 1 were introduced as convenient criteria for judging the possibilities for thermal damage Lundskog (1972) reported osteocyte necrosis for cells that were exposed to a temperature of 50 C for only 30 seconds If this criterion is used it is apparent looking at the data presented in table 7 V that in the case of intramedullary stem fixation osteocyte necrosis within a region of 0 1 5 mm of the cortex is a distinct possibility In the case of the rabbit femur necrosis would still be improbable

However uncertain these conclusions are in an absolute sense it is clear that bone prosthesis systems are not designed within their safety limit where thermal damage is concerned An overall conclusion with respect to intramedullary fixation of implants can be that the temperature in the bone could reach values that might well give rise to bone necrosis

More certainty can be had by narrowing the possible ranges of parameter values by means of experiment Theoretical analyses as presented here provide guidelines for such experi ments From the results of the parametric analyses it is evident that the following properties should then be specially evaluated with greater accuracy

- the thermal conductivity of the cement bone interface
- the bone and local blood temperature prior to insertion of the cement
- the heat transport mechanism at the bone surface
- the thermal conductivity of cortical bone

7 9 A hypothesis on thermal tissue damage by acrylic cements

An extensive histological study concerning adverse side effects of acrylic cement was con ducted by Feith (1975) He treated different groups of rabbits with (1) suction and reaming of the femoral intramedullary canal (RS) (2) RS and a pre polymerized rod of acrylic cement (residual monomer and no heat) (3) RS and a commercial cement mixture to poly merize in situ (residual monomer and heat) (4) RS and a cement mixture without catalyser (overdose monomer and no heat) and (5) RS and a mixture of an experimental aqueous gel cement to polymerize in situ (residual monomer and minor heat) He concluded that reaming and residual monomer especially an overdose cause bone necrosis at the interface but that the principal causative factor is the heat of polymerizing.

By simulating the case in which a medullar cavity of a rabbit bone is filled with acrylic cement it was shown in this chapter that results of such experiments cannot simply be applied to human circumstances owing to the different dimensions These results indicated that it is very unlikely that in the rabbits of Feith (1975) the thermal effect was the princi pal causative factor in bone necrosis In his different groups he did not isolate the thermal effect but the heat was always present together with residual monomer The results of his different groups on which he based his conclusions are schematically summarized in fig. 7 16 only as regards necrosis of the inner cortex (Feith studied other effects as well)
Also shown in fig. 7 16 is an extrapolation of the results obtained here presented as a

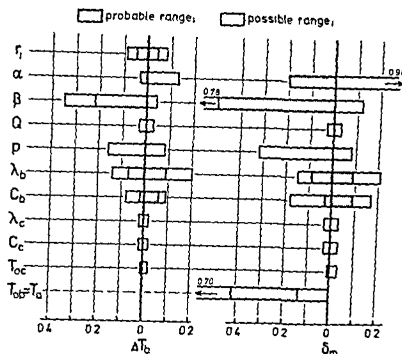


fig 7 15 The influences of the probable and possible ranges of parameter values on ΔT_b and δ_m The influences are given as maximal negative and positive deviations from the reference values

case	reference value		probable range	
	T_b (°C)	δ_m (mm)	T_b (°C)	δ_m (mm)
reference calculation (no implant)	59	1 6	51 62	0 1 9
implant present (thickness 12 mm)	54	1 3	48 57	0 1 5
rabbit femur (no implant)	48	0	44-50	0

table 7 V Probable ranges of T_b and δ_m in three cases, as calculated using the combined effects of the probable ranges in the parameter values, as shown in fig 7 15, except $T_{0b} = T_a$ (see also text)

be $\{1 - (1 + f_1)(1 + f_2)\})$ Results of applications for a few cases are shown in table 7 V In this table the influence of $T_{0b} = T_a$ is not taken into account In the reference case $T_{0b} = T_a = 37°C$ however, the local bone and blood temperatures during an operation are probably lower (d Hollander *et al*, 1976)
Using the factors for the possible parameter ranges in fig 7 15 a possible range in T_b and δ_m could be calculated also However, it is improbable although possible, that an individual parameter has a value outside its probable range but it is quite improbable that all parameters exceed their probable upper and lower boundaries simultaneously Moreover since the combined influences were assumed to be independent in this calculation it is doubtful whether, for such large deviations of the parameters from their reference values such a calculation still has any realistic significance
Based on the data shown in table 7 V and the threshold curve in fig 3 1 the cautions conclusion can be drawn that during fixation of intramedullary stems tissue necrosis of the

CHAPTER EIGHT

TEMPERATURE VALUES DURING ACETABULAR CUP FIXATION

In this chapter a heat generation and conduction analysis of acrylic cement during acetabular cup fixation will be presented A schematic cross-section of the bone prosthesis system concerned is shown in fig 8 1 In the model used for the analysis the (plastic) cup the cement layer and a part of the (spongeous) acetabular bone (as shown in fig 8 1) are taken into account Heat loss from the bone in the model to the adjoining bone or soft tissues is described by the boundary conduction and convection coefficient α The model is axi symmetric and although this does not give a very accurate geometrical description of the real system as far as the bone is concerned it will at least give a more or less accurate description of the heat conduction process in the frontal plane

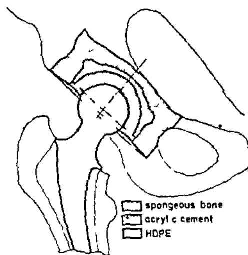


fig 8 1 Schematic frontal section of an acetabular cup fixation system, indicating the part of the acetabulum that is taken into account in the model

The model and its parameters are shown in fig 8 2 the parameter values used in the analysis are summarized in table 8 1

Fig. 8 3 shows the element mesh for the model as generated by computer program (Schoofs *et al* 1978) Time dependent temperatures were calculated as described in chapter 4 for all nodal points The nodal points the results of which will be considered are shown in fig. 8 4 These points are located more-or less on three lines (1 2 and 3) The points on line 2 are numbered as shown

Temperatures as a function of time as calculated for these points are shown in fig 8 5 The temperature in the middle of the cement mass (point 7) reaches a maximal value of approximately 110 C the bone at the cement bone interface (point 10) a value of approximately 57 C and the HDPE at the cement implant interface (point 4) approximately 69°C

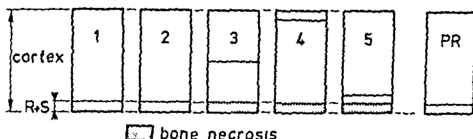


fig 7 16 Schematic summary of results reported by Feith (1 through 5) and an extrapolation of results of the present work (PR), with respect to inner cortical necrosis of rabbit femurs after filling of the medular cavity with acrylic cement Parameters are reaming and suction (RS), residual monomer (M) and heat of polymerizing (H) 1 RS only, 2 RS + M, 3 RS + M + H, 4 RS + M (overdose), 5 RS + M + H (little heat), PR RS + H

hypothetical sixth group where reaming and suction and heat of polymerizing would be applied and in which as was predicted by the rabbit model calculations, the amount of bone necrosis would be the same as in reaming and suction only
As there appears to be no reason to doubt the findings of Feith and because the present analysis has shown that the heat of polymerizing alone (a case that he did not investigate) would most probably not induce tissue necrosis in the rabbit the hypothesis can be put forward, following directly from fig 7 16 that the necrotic effect of the residual monomer would be more pronounced at higher temperatures so that the temperature has an indirect effect rather than a direct effect

fig 8 3 The element mesh used in the computer simulation

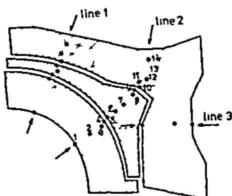


fig 8 4 Points roughly located on three lines of which those on line 2 are numbered the temperatures as calculated at these points are discussed in the text

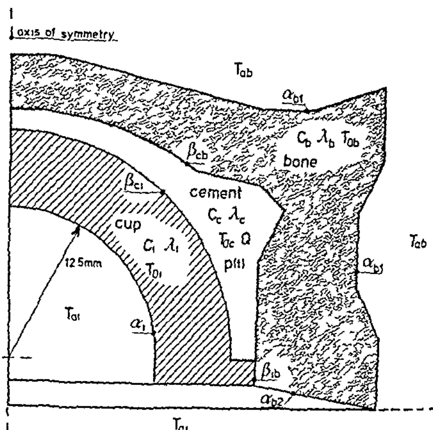


fig 8 2 The (axisymmetric) model giving the parameters of the process of heat generation and conduction

parameter	unit	value	parameter	unit	value
heat generation			cement		
Q	J/m^3	$1\ 7\times10^8$	C_c	$J/m^3{}^\circ C$	$1\ 75\times10^6$
p(t)	–	$p_1(t)$	λ_c	J/msec°C	0 17
t_r	sec	0	T_{0c}	°C	25
τ	sec	350			
interface conditions			bone (spongeous)		
β_{ci}	$J/m^2sec^\circ C$	500	C_b	$J/m^3{}^\circ C$	$3\ 0\times10^6$
β_{cb}	$J/m^2sec^\circ C$	500	λ_b	J/msec°C	0 4
β_{ib}	$J/m^2sec^\circ C$	500	T_{0b}	°C	37
boundary conditions			cup (HDPE)		
α_i	$J/m^2sec^\circ C$	10	C_i	$J/m^3{}^\circ C$	$2\ 2\times10^6$
α_{b1}	$J/m^2sec^\circ C$	10	λ_i	J/msec°C	0 29
α_{b2}	$J/m^2sec^\circ C$	500	T_{0i}	°C	25
T_{ai}	°C	25			
T_{ab}	°C	37			

table 8 1 Values as used for parameters in the acetabular cup model

From the calculated time dependent temperatures the liability of the bone to vascular damage or bone cell necrosis was estimated using the threshold level curves of fig 3 1, taking temperature values as well as the exposure times into account From this evaluation a necrosis map as shown in fig 8 7 evolves also shown on this map is the region in the cement that reaches over 100°C and would therefore be liable to monomer evaporation This necrosis map gives an indication of the region most probably damaged and should not be regarded in too absolute a sense since some parameter values are somewhat uncertain and the thermal damage threshold curves of fig 3 1 also have uncertain aspects If the data presented by Lundskog (1972) were taken as a threshold criterion (cell necrosis after exposure for 30 seconds to 50°C) a much larger part of the bone would be liable to necrosis as indicated in fig 8 7

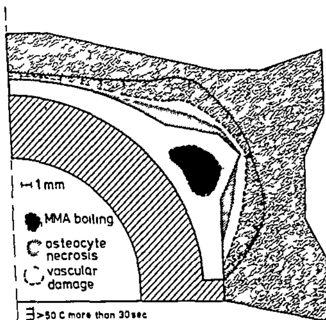


fig 8 7 A necrosis map as constructed from the calculated results giving a rough impression of parts of the bone liable to osteocyte necrosis and vascular damage using the time-dependent threshold levels in fig 3 1 as criteria also indicated is the part of the bone that would be liable to osteocyte necrosis if the data of Lundskog (1972) were used as a criterion (necrosis after 30 sec at 50°C)

This model is not so well suited for extensive parametric analyses as the model discussed in the previous chapter owing to its greater geometrical complexity It has been shown however that the values of α have little influence on the maximal temperatures of cement and bone The parameters that exert a significant influence on the bone temperatures and whose values are somewhat uncertain are β_{cb} λ_b C_b and T_{0b} The values of T_{0b} and T_a will probably be higher than in the system previously analysed owing to the fact that the system is enclosed by much soft tissue and highly vascularized spongeous bone Thanks to the many and more dependable results published on the properties of spongeous bone

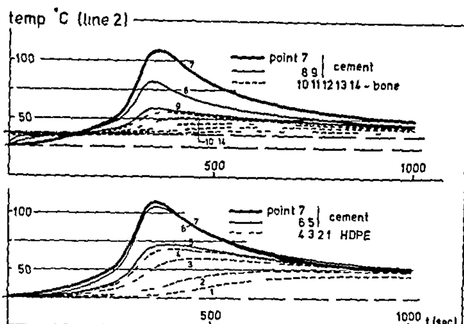


fig 8 5 Temperature as a function of time at the 14 points indicated in fig 8 4, as cal culated in the computer simulation (top graph cement and bone, bottom graph cement and cup, the temperature of point 7 (in the middle of the cement mass) is drawn in both graphs)

The temperatures in the HDPE are higher than those in the bone, due to the superior heat capacity and conductivity properties of the latter material, but also to the smaller area of the cup cement interface compared to the cement bone interface
For the three 'lines' shown in fig 8 4, time dependent penetration depths of the 45, 50, 55 and 60°C isotherms into the bone ($\delta(t)$) have been calculated, as shown in fig 8 6
On line' 3 especially, a relatively large part of the bone will be liable to tissue necrosis, as can be concluded on comparing these graphs with the time dependent threshold level in fig 3 1 The high temperature values at 'line' 3 are caused by the circumstance that the bone is somewhat surrounded by cement here The lowest maximal temperature values are reached at line 1 due to the relatively thin cement mantle in this region

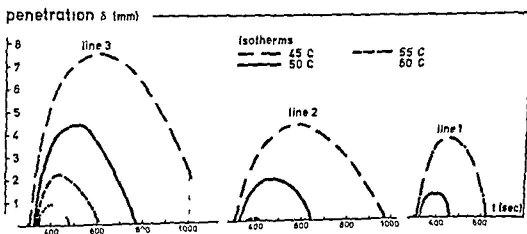


fig 8 6 Penetration depths of the 45 50, 55 and 60°C isotherms into the bone on lines 1, 2 and 3 as functions of time

From the calculated time-dependent temperatures the liability of the bone to vascular damage or bone cell necrosis was estimated using the threshold level curves of fig 3 1, taking temperature values as well as the exposure times into account From this evaluation a necrosis map as shown in fig 8 7 evolves also shown on this map is the region in the cement that reaches over 100°C and would therefore be liable to monomer evaporation This necrosis map gives an indication of the region most probably damaged and should not be regarded in too absolute a sense since some parameter values are somewhat uncertain and the thermal damage threshold curves of fig 3 1 also have uncertain aspects If the data presented by Lundskog (1972) were taken as a threshold criterion (cell necrosis after exposure for 30 seconds to 50°C) a much larger part of the bone would be liable to necrosis as indicated in fig 8 7

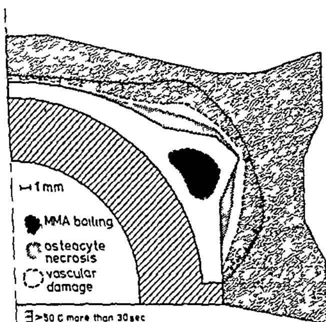


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compared to cortical bone, greater confidence can be given to the values of λ_b and C_b than in the previous model (see also table 5 VI) Inaccuracies in the predicted temperature values would thus for the greater part be due to uncertainty in the value of β Of course, it should not be forgotten that the geometry chosen for the model is a more or less general representation of the many possible ones in reality and that individual differences in maximal temperature values might thus occur to a greater or lesser extent
Due to variations in β only, the probable temperature increase in the bone could vary from approximately 0 8 to 1 0 times the calculated values Due to the fact that the cement is fixated to spongeous bone, somewhat lower values for β may be expected compared to those in the previous model

In conclusion it can be said that owing to geometrical circumstances, but also to a higher initial bone temperature and the inferior thermal properties of HDPE compared to metal, there will be a greater chance for thermal damage during acetabular cup fixation than during fixation of intramedullary (metal) implants If such damage occurs, a zone of about 1 2 mm will be affected, but in specific regions a larger zone (4 5 mm) may be liable to damage The chance of thermal necrosis can be reduced in this case, apart from the measures to be discussed in the next chapter, by smoothening the (macro) geometry of the bony implant bed and by avoiding the application of large cement masses

CHAPTER NINE

MEASURES FOR DIMINISHING THE CHANCES OF THERMAL TISSUE DAMAGE

As was shown in chapter 7 some options are available to reduce the maximal temperatures in the system because the process of heat generation and conduction is quite sensitive to some of the parameters that can be influenced either by the surgeon or by the cement manufacturer Experiments with a number of the possible measures have been published in the literature for instance the addition of such heat sinks as radiopaque fillers titanium dioxide (Homsy *et al* 1972) crystalline monomers (Lee and Turner 1977) or aqueous gels (de Wijn *et al*, 1978) retardation of the polymerization curve (de Wijn 1974) and pre cooling of the cement or the implant (Ohnsorge and Goebel 1970 Meyer *et al* 1973 Dipisa *et al*, 1976)
Some of the possible measures will be evaluated as to their effect on the maximal tempera ture values in the bone prosthesis system on the basis of the parametric analysis discussed in chapter 7

9 1 Adding heat sinks to the powder

When a heat sink is added to the powder in other words when a material with superior heat capacity properties is substituted for a part of the polymer powder both the heat capacity and the thermal conductivity of the mixture are affected
If the weight ratio additive/powder is denoted by μ the heat capacity C_c of the mixture can be calculated using formula (5 6) (paragraph 5 3) The influences of the changed value of C_c on the temperature increases (ΔT_c ΔT_b) and the penetration depth of the 50°C isotherm (δ_m) in the model described in paragraph 7 1 can be evaluated using fig 7 13 For added barium sulfate (ρ = 4 5x10³ kg/m³ C = 1 96x10⁶ J/m³ C) and zirconium oxide (ρ = 5 6x10³ kg/m³ C = 3 91x10⁶ J/m³ C) this evaluation was carried out neglecting the influence on the thermal conductivity and assuming a constant value of ν_m (0 35)

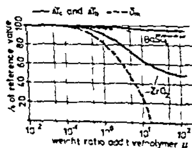


fig 9 1 Approximative influence of the amounts of barium sulfate and zirconium oxide added to the powder on the maximal temperature increase of the cement (ΔT_c) of the bone (ΔT_b) and on the penetration depth of the 50° isotherm as percentages of the reference values (reference case ΔT_c = 101°C, ΔT_b = 22°C and δ_m = 1 6 mm) (100% = no additives)

compared to cortical bone, greater confidence can be given to the values of λ_b and C_b than in the previous model (see also table 5 VI) Inaccuracies in the predicted temperature values would thus for the greater part be due to uncertainty in the value of β Of course, it should not be forgotten that the geometry chosen for the model is a more or less general represen tation of the many possible ones in reality and that individual differences in maximal tem perature values might thus occur to a greater or lesser extent
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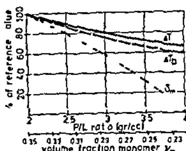


fig 9 3 *Approximative influence of the P/L ratio on ΔT_c, ΔT_b and δ_m as percentages of the reference values (100% = 2 gr/cc)*

9 4 Retarding the polymerization process

The polymerization function especially the auto-acceleration effect can be retarded with chemical additives (de Wijn 1974) The auto acceleration effect is characterized by the maximal polymerization rate (θ_p = max(dp/dt)) The influence of retardation as evaluated by using the polymerization functions p_1 p_2 and p_3 in chapter 7 on ΔT_c, ΔT_b and δ_m is shown in fig 9 4 where $1/\theta_p$ is chosen for the variable and 100% is taken for idealized snap curing cement For interpretation of these graphs it is convenient to note that when $1/\theta_p$ = 200 sec the auto acceleration period would be approximately twice as long compared to $1/\theta_p$ = 100 sec

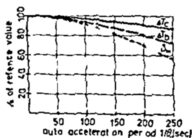


fig 9 4 *Approximative influence of the rate of polymerization (the auto-acceleration effect) on ΔT_c ΔT_b and δ_m the variable on the horizontal axis is the inverse of the maximal polymerization rate (100% = snap-curing)*

9 5 Pre-cooling the operation region

As was shown in chapter 7 the bone temperature prior to insertion of the cement and the ambient (local blood) temperature exert a marked influence on the maximal temperatures in the bone It would be possible to cool the local operation region prior to insertion with a

For these two additives fig 9 1 shows the influence of the weight ratio μ on the cement temperature increase (ΔT_c), the bone(interface) temperature increase (ΔT_b) and the pene tration depth (δ_m), expressed as percentages of their reference values, as evaluated in chapter 7 Evidently the addition of $BaSO_4$ has only a minor influence, adding ZrO_2 has considerably more effect However, for $\mu = 1$, the decrease in ΔT_c and ΔT_b is only about 10% and the decrease in δ_m about 20%

9 2 Adding an aqueous gel to the mixture

If an aqueous gel is added to the cement in other words, is substituted for a part of the cement a porous cement will result when used for implantation (e g de Wijn *et al*, 1978) In this case the amount of heat generated per unit volume of mixture, the heat capacity of the mixture and the thermal conductivity are affected If it is assumed that the volume ratio between the polymer and the monomer remains constant, ν_m can be calculated for a given *volume fraction of gel (ν_{ac}) by using formula (5 2) (paragraph 5 1) and C_c can be calculated* using formula (5 7) (paragraph 5 3) For the thermal conductivity it is assumed that $\lambda_c = \lambda_c' + \nu_{ac} (\lambda_{ac} - \lambda_c')$, where λ_c' is the conductivity of only the acrylic part of the mixture Assuming that the influence of the changes in the three parameters are exerted independent ly, the effect of the changes combined can be approximated using the results described in chapter 7 This was carried out taking the thermal properties of the gel as those of water Fig 9 2 shows the influence of the volume fraction of gel in the mixture on the temperature increases ΔT_c and ΔT_b and the penetration depth δ_m, as percentage changes with respect to their reference value Apparently this measure has a marked influence on the temperatures

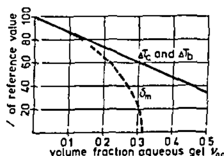


fig 9 2 Approximative influence of the amount of aqueous gel added to the cement mixture on ΔT_c, ΔT_b and δ_m as percentages of the reference values (100% = no gel added)

9 3 Increasing the P/L ratio

If the P/L ratio is increased ν_m and hence Q are decreased The influence of this measure, that can be evaluated directly from figs 5 1 and 7 10 is shown in fig 9 3

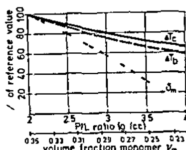


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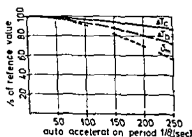


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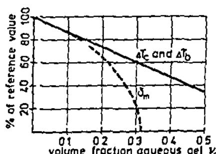


fig 9 2 Approximative influence of the amount of aqueous gel added to the cement mixture on ΔT_c, ΔT_b and δ_m as percentages of the reference values (100% = no gel added)

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If the P/L ratio is increased, ν_m and hence Q are decreased The influence of this measure that can be evaluated directly from figs 5 1 and 7 10 is shown in fig 9 3

Another possibility would be where large cement masses are required to use prefabricated plastic for instance in coated stems
It should be noted that some of the possible measures affect the quality (strength) of the cement (see section I) for instance heat sink additives to the powder drastic increase of the P/L ratio and the addition of aqueous gels So they should not be applied over the full range of their possibilities
However good results can be expected if some of the measures were taken in combination If 10 volume % aqueous gel were added to the mixture, the P/L ratio would be increased from 2 gr/cc to 2 25 gr/cc the auto acceleration effect would be retarded by 100 sec and the operation region would be cooled to 30°C prior to and during the polymerization, the maximal rise of the bone temperature would decrease by about 50% thus in most cases banishing the chances of thermal bone necrosis completely

physiological water solution Fig 9 5 once more shows the effect of this measure on ΔT_c, ΔT_b and δ_m

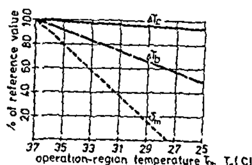


fig 9 5 Approximative influence of the bone and the local blood temperatures prior to the polymerization process on ΔT_c, ΔT_b and δ_m (100% = local bone and blood temperatures of 37°C)

9 6 Conclusions

Other measures than those discussed in this chapter would be possible, as for instance pre cooling of the cement and the implant Although this would certainly reduce the tempera ture values, it was shown in chapter 7 that, for instance pre cooling of the cement to 15°C has only a minor influence on the bone temperature, it was also shown in the literature (e g Ohnsorge and Goebel, 1970, Dipisa *et al*, 1976) that more drastic pre cooling seriously prejudices the polymerization process
Another possibility would be, at least in theory, to protect the bone by increasing the heat flow resistance at the cement bone interface in other words, by decreasing β How this could be done in reality is not clear at the moment, some thin protective layer with low thermal conductivity would be the answer In this respect it can also be concluded that a thorough cleansing of the bony implant bed prior to cement insertion is not advantageous and would, at least locally increase the chances of thermal bone necrosis An effective measure that could be taken by the surgeon as has been illustrated in chapters 7 and 8 is to avoid large cement masses and restrict the thickness of the cement layers Fig 9 6 once more shows the influences of the (metal) implant thickness (hence the cement mantle thickness) on ΔT_c ΔT_b and δ_m in intramedullary stem fixation

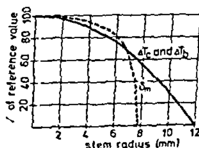


fig 9 6 Approximative influence of the (metal) stem thickness (hence also the cement layer thickness s) on ΔT_c, ΔT_b and δ_m (100% = no implant present)

with respect to the thermal threshold levels for cell necrosis are not significantly different (e g. Kuhl *et al*, 1954 Lundskog 1972 Feith 1975) As was shown here, however, the differences in their levels more or less coincide with the upper and lower boundaries of the probable bone temperature values Hence narrowing of this probable range would give no better answer More progress could be expected from applying more detailed theoretical analyses of the cement bone interface region using the approximative results presented here as boundary conditions and combining the theoretical studies with experimental histological data

It was established that results of animal experiments are not representative of humans as far as heat generation and conduction aspects are concerned owing to the differences in dimensions
By simulating the rabbit experiments of Feith (1975) and combining the theoretical and experimental results the hypothesis evolved that the temperature has an indirect effect by means of the influences on the monomer reactions rather than a direct effect on the tissue necrosis Whether this is true or not it would in any case be better to reduce the tempera tures as much as possible This can certainly be accomplished by *taking certain precautions* *In the* literature some possible ones have been investigated the measures proposed were mostly partial and drastic most often resulting in a cement of inferior quality It could be established here that certain quite simple and effective measures can be taken that will not prejudice the cement quality and that very good results can be expected if a number of slight measures are combined
The most remarkable influence is exerted by the local bone and blood *temperature prior to* cement insertion It should be quite possible to cool this *region to* 30°C *or even* 25 C *which will* drastically decrease the maximal bone temperatures Also the cement layer di mensions could be restricted as far as possible and the geometry of the implant bed could be made smooth and concave in the macroscopic sense
The in situ curing cement is in essence only needed to adapt the smooth implant to the *irregular bone* Hence the thickness of this cement layer would not *necessarily have to be* more than dictated by the dimensions of the irregularities Where only *fillings are required* pre polymerized materials could be used as well

CHAPTER TEN

DISCUSSION

In this section the process of heat generation and conduction of acrylic cement in situ has been analysed By making certain assumptions as to the properties of the cement and the bone material, and by approximating the geometry of the bone prosthesis system by axi symmetry, the heat generation and conduction process was mathematically described on the basis of the conservation of energy principle and Fourier's law The equations have been solved using a computer program applying FEM and backward time discretization Based on a literature review, values for parameters used in the models were estimated Relatively little was found to be known about these parameters, hence, in some cases only a range of probable values could be established This range will, no doubt, also reflect the individual differences where biological material is concerned and random compositional differences where acrylic cement is concerned Due to the uncertainties as regards parameter values the use of more refined mathematical models would in this respect, not be justified as yet Unfortunately the influence of the temperature on the polymerization process itself could not be taken into account, owing to lack of knowledge about this relation in the mathematical model and the solution procedure chosen here this influence can easily be accounted for By simulation of two experiments published in the literature, the applicability of the model and the appropriateness of the chosen parameter values have been evaluated to some extent and it was shown that the method can in fact be used to predict the time dependent temperature values by approximation Based on a literature review, threshold levels for thermal tissue damage were evaluated As was to be expected here too, no exact value for this level evolved Taking the upper and lower boundaries of all dependable published data one could say that for a bone temperature above 60°C bone necrosis is probable and for a temperature below 48°C it is improbable Between 48 and 60°C it depends on the exposure time, for a temperature of 50°C the threshold exposure time may be between 30 sec (Lundskog, 1972) and 400 sec (Moritz and Henriques, 1947) as regards cell necrosis In analyzing a number of situations in which bone cement is used for fixation of implants it was found that the maximal bone temperature values to be expected are precisely within this range Because of this no definite answer can be given to the question whether thermal damage occurs or not, the possibilities certainly exist and much will depend on the specific circumstances No doubt this is also the reason for the variety in results of animal and laboratory experiments published on this problem

It was shown that in surface fixation using plastic implants for instance the acetabular cup there is a higher chance of bone necrosis than in intramedullary fixation using metal implants Nevertheless in the first case, too the maximal bone temperature will probably not be higher than 60°C The higher temperatures that have been reported in the literature were probably measured in the cement part of the cement bone interface Very high temperatures will only occur locally in the tips of trabeculae surrounded by cement More definite data could be obtained in using the methods described here if certain properties of the bone prosthesis system were established with better accuracy by experiment Guidelines for such experiments as followed from the analyses, have been discussed in chapter 7 Due to individual differences and random influences however, a considerable scatter in the data will always remain It is, for instance frequently mentioned in the literature that the results of Moritz and Henriques (1947), Kuhl *et al* (1954) and Lundskog (1972)

d Hollander, A Burny F Monteny E and Donkerwolcke M (1976) Extra-osseous variations of temperature during polymerization of acrylic cement in hip arthroplasties Acta Orthop Scand 47 pp 186-188
Homsy C.A Tullos H S Anderson M S Differante N M and King J W (1972) Some physiological aspects of prosthesis stabilization with acrylic polymer Clin Orthop and Rel Res 83 pp 317 328
Huiskes R (1977) Warmte afvoer van zelfhardend botcement Report no RH 77 02 Lab Exp Orthop Dept Orthop Univ of Nijmegen The Netherlands
Huiskes R., de Wijn J R Slooff, T J J H and van Rens Th J G (1977), Thermodynamic FEM analysis of self curing bone cements (PMMA) 1st Eur Conf on Evaluation of Biomaterials Strasbourg September (acc for publication in Advances in Biomaterials Winter and Leray eds)
Huiskes R (1978) Warming up of acrylic cement assuming non linear heat capacity properties unpublished data
Huiskes R and Slooff T J J H (1978) Temperature values in bone tissue during implantation of self curing PMMA Eur Soc of Biomaterials Brussels May
Huiskes R and de Wijn J R (1978) Heat conduction in acrylic bone cement a thermodynamic analysis 24th Ann Meeting Orthop Res Soc Dallas Tex Febr (publ Transactions J Bone Jt Surg vol 2 no 1)
Huiskes R (1979a) Thermal tissue damage by acrylic cements 25th Ann Meeting Orthop Res Soc San Francisco Cal February (to be published in Transactions J Bone Jt Surg 1979)
Huiskes R (1979b) Solution of the diffusion convection equation using FEM Report ORa 79 05 Lab Exp Orthop Dept Orthop Univ of Nijmegen The Netherlands
Huiskes R de Wijn J R and Slooff T J J H (1979) Heat analysis of self curing PMMA as used in bone cements 3rd Int Conf Plastics in Med and Surg Enschede Netherlands June
Hupfauer W und Ulatowski L (1972) Die Temperaturenentwicklung verschiedener Knochenzemente wahrend des Abhartungsvorganges Arch Orthop Unfall Chir 72 174-184
Jacobs R B and Starr C (1939) Thermal conductance of metallic contacts Rev Scient Instrum 10 140
Jefferiss C D Lee A J C and Ling R S M (1975) Thermal aspects of self curing polymethylmethacrylate J Bone Jt Surg 57 B no 4 pp 511 518
Kaye G W C and Laby T H (1959) Tables of physical and chemical constants and some mathematical functions Longmann London
Kuhl P R Sheline G E and Alpen E L (1954) Blister formation and tissue temperature in radiant energy and contact burns Amer J Pathol 30 p 695
Kummer B K F (1972) Biomechanics of bone In Biomechanics its foundation and objective C Fung ed) Englewood Cliffe N J Prentice Hall
Labitzke Paulus M (1974) Intraoperative Temperaturmessungen in der Hüftchirurgie wahrend der Polymerisation des Knochenzementes Palacos Arch Orthop Unfall Chir 79 341 346
Leach E H Peters R A and Rossiter R J (1943) Experimental thermal burns especially the moderate temperature burn Quart J Exp Physiol 32 67
Lee H B and Turner D T (1977) Temperature control of a bone cement by addition of crystalline monomer J Biomed Mat Res 11 671 676
Lehnartz E (1959) Chemische Physiologie Springer Verlag Berlin Gottingen Heidelberg
Lundskog J (1972) Heat and bone tissue Scand J of Plastics and Reconstr Surg suppl 9
Meyer J R Lautenschlager E P and Moore E K (1973) On the setting properties of acrylic bone cement J Bone Jt Surg 55 A 149 156

REFERENCES

Balasubramanian, T A , Bowman, H F Woods, M and Judge, A (1977), Thermal transport *properties of selected human tissues, paper no 125, 3th Ann Meeting of the Soc for* Biomaterials, New Orleans Louisiana

Barrett, E P , Jonnard, A and Missmer, J H (1953), Some physical properties of bone char *and synthad , Indust Eng Chem 45, 1524 1526*

Biehl, G , Harms, J and Hauser, U (1974), Experimentelle Untersuchungen uber die Warme entwicklung im Knochen bei der Polymerisation von Knochenzement, Arch Orthop *Unfall Chir 78, 62 69*

Bowman, H F , Murphy, K G , Balasubramanian M and Judge, A (1979), Thermal conduc tivity of selected human tissue, 5th Ann Meeting Soc Biomaterials, Clemson, So Car April May

Brekelmans, W A M (1975), Een werkwijze voor het numeriek oplossen van een bepaald type elliptische differentiaalvergelijkingen, Report WE 75 03, Dept Applied Mech , Mech Eng , Eindhoven Univ of Technology

Cameron, H U , Jacob, R , McNab I and Pilliar, R M (1975), Use of polymethylmethacry late to enhance screw fixation in bone, J Bone Jt Surg 57 A, no 5, 655 656

Carlslaw H S and Jaeger, J C (1959), Conduction of heat in solids, Oxford Univ Press

Charnley, J (1970), Acrylic cement in orthopaedic surgery, E and S Livingstone, Edinburgh and London

Chato, J C (1965), A survey of thermal conductivity and diffusivity data on biological materials, 5th Conf on Thermal Conductivity, Vol 2, sessions IV VI, Denver, Col

Clattenburg, R , Cohen J Conners, S and Cook, N (1975), Thermal properties of cancellous bone, J Biomed Mat Res , vol 9, 169 182

Cohen, J (1978), Private communication

Debrunner, H U , Wettstein, A and Hofer P (1976) The polymerization of selfcuring acrylic cements and problems due to the cement anchorage of joint prostheses, In Advances in Artificial Hip and Knee Joint Technology, (Schaldach, M and Hohmann, D , eds), Springer Verlag, Berlin Heidelberg New York

Dipisa J A Sih, G S and Berman A T (1976), The temperature problem at the bone acrylic cement interface of the total hip replacement, Clin Orthop and Rel Res 121, 95 98

D Souza N , Stachiewicz J W , Miller J Ahmed, A M and Burke D L (1977), Thermal analysis of axisymmetric bone implants using selfcuring polymethylmethacrylate paper no 57 3rd Ann Meeting of the Soc for Biomaterials, New Orleans Louis

Eckert E R G and Drake R M Jr (1972), Analysis of heat and mass transfer, McGraw Hill Kogakusha Tokyo

Feith R (1975), Side effects of acrylic cement implanted into bone Suppl nr 161 Acta Orthop Scand

Frados J (ed) (1966), Modern Plastics Encyclopedia 1967 Modern Plastics vol 44, p 41

Fried, E (1969), Thermal conduction contribution to heat transfer at contacts, In Thermal conductivity (Tye R P , ed) Acad press London and New York

Graf, K und Stein E (1957), Fortlaufende Registrierung der Knochenmarkdurchblutung des Menschen mit der Warmeleitsonde Zeitschrift f die gesamte exp Medizin Bd 129 s 1 14

Grober Erk und Grigull (1961), Warmeubertragung Springer Verlag Berlin

Henschel C J (1943) Heat impact of revolving instruments on vital dentin tubules, J Dent Res no 22, p 323

d Hollander A Burny F Monteny E and Donkerwolcke M (1976) Extra-osseous variations of temperature during polymerization of acrylic cement in hip arthroplasties Acta Orthop Scand 47 pp 186-188
Homsy C A Tullos H S Anderson M S Differante N M and King J W (1972) Some physiological aspects of prosthesis stabilization with acrylic polymer Clin Orthop and Rel Res 83 pp 317 328
Huiskes R (1977) Warmte afvoer van zelfhardend botcement Report no RH 77 02 Lab Exp Orthop Dept Orthop Univ of Nijmegen The Netherlands
Huiskes R de Wijn J R Slooff T J J H and van Rens Th J G (1977), Thermodynamic FEM analysis of self curing bone cements (PMMA) 1st Eur Conf on Evaluation of Biomaterials Strasbourg September (acc for publication in Advances in Biomaterials Winter and Leray eds)
Huiskes R (1978) Warming up of acrylic cement assuming non linear heat capacity properties unpublished data
Huiskes R and Slooff T J J H (1978) Temperature values in bone tissue during implantation of self curing PMMA Eur Soc of Biomaterials Brussels May
Huiskes R and de Wijn J R (1978) Heat conduction in acrylic bone cement a thermodynamic analysis 24th Ann Meeting Orthop Res Soc Dallas Tex Febr (publ Transactions J Bone Jt Surg vol 2 no 1)
Huiskes R (1979a) Thermal tissue damage by acrylic cements 25th Ann Meeting Orthop Res Soc San Francisco Cal February (to be published in Transactions J Bone Jt Surg 1979)
Huiskes R (1979b) Solution of the diffusion convection equation, using FEM Report ORa 79 05 Lab Exp Orthop Dept Orthop Univ of Nijmegen The Netherlands
Huiskes R de Wijn J R and Slooff T J J H (1979) Heat analysis of self curing PMMA as used in bone cements 3rd Int Conf Plastics in Med and Surg Enschede Netherlands June
Hupfauer W und Ulatowski L (1972) Die Temperaturenentwicklung verschiedener Knochenzemente wahrend des Abhartungsvorganges Arch Orthop Unfall -Chir 72 174-184
Jacobs R B and Starr C (1939) Thermal conductance of metallic contacts Rev Scient Instrum 10 140
Jefferiss C D Lee A J C and Ling R S M (1975) Thermal aspects of self curing polymethylmethacrylate J Bone Jt Surg 57 B no 4 pp 511 518
Kaye G W C and Laby T H (1959) Tables of physical and chemical constants and some mathematical functions Longmann London
Kuhl P R Sheline G E and Alpen E L (1954) Blister formation and tissue temperature in radiant energy and contact burns Amer J Pathol 30 p 695
Kummer B K F (1972) Biomechanics of bone In Biomechanics its foundation and objective ' C Fung ed) Englewood Cliffe N J Prentice Hall
Labitzke Paulus M (1974) Intraoperative Temperaturmessungen in der Hüftchirurgie wahrend der Polymerisation des Knochenzementes Palacos Arch Orthop Unfall Chir 79 341 346
Leach E H Peters R A and Rossiter R J (1943) Experimental thermal burns especially the moderate temperature burn Quart J Exp Physiol 32 67
Lee H B and Turner D T (1977) Temperature control of a bone cement by addition of crystalline monomer J Biomed Mat Res 11 671 676
Lehnartz E (1959) Chemische Physiologie Springer Verlag Berlin Gottingen Heidelberg
Lundskog J (1972) Heat and bone tissue Scand J of Plastics and Reconstr Surg suppl 9
Meyer J R Lautenschlager E P and Moore E K (1973) On the setting properties of acrylic bone cement J Bone Jt Surg 55 A 149 156

REFERENCES

Balasubramanian, T A , Bowman, H F , Woods, M and Judge, A (1977), *Thermal transport properties of selected human tissues*, paper no 125, 3th Ann Meeting of the Soc for Biomaterials New Orleans, Louisiana

Barrett, E P , Jonnard, A and Missmer, J H (1953), *Some physical properties of bone char and synthad , Indust Eng Chem 45, 1524-1526*

Biehl, G , Harms, J and Hauser, U (1974), Experimentelle Untersuchungen uber die Warme entwicklung im Knochen bei der Polymerisation von Knochenzement Arch Orthop Unfall Chir 78, 62 69

Bowman, H F , Murphy, K G , Balasubramanian, M and Judge, A (1979), *Thermal conductivity of selected human tissue*, 5th Ann Meeting Soc Biomaterials, Clemson, So Car , *April May*

Brekelmans, W A M (1975), Een werkwijze voor het numeriek oplossen van een bepaald type elliptische differentiaalvergelijkingen, Report WE 75 03, Dept Applied Mech , *Mech Eng , Eindhoven Univ of Technology*

Cameron, H U , Jacob, R , McNab, I and Pilliar, R M (1975), Use of polymethylmethacrylate to enhance screw fixation in bone, J Bone Jt Surg 57 A, no 5, 655 656

Carlslaw H S and Jaeger J C (1959), Conduction of heat in solids Oxford Univ Press

Charnley, J (1970), Acrylic cement in orthopaedic surgery, E and S Livingstone, Edinburgh *and London*

Chato, J C (1965), *A survey of thermal conductivity and diffusivity data on biological materials, 5th Conf on Thermal Conductivity, Vol 2, sessions IV VI, Denver, Col*

Clattenburg, R , Cohen, J , Conners, S and Cook, N (1975), Thermal properties of cancellous bone, J Biomed Mat Res vol 9, 169 182

Cohen, J (1978), *Private communication*

Debrunner, H U Wettstein, A and Hofer, P (1976), *The polymerization of selfcuring acrylic cements and problems due to the cement anchorage of joint prostheses*, In Advances in Artificial Hip and Knee Joint Technology, (Schaldach, M and Hohmann D eds) Springer Verlag, Berlin Heidelberg, New York

Dipisa J A Sih, G S and Berman A T (1976) *The temperature problem at the bone* acrylic cement interface of the total hip replacement, Clin Orthop and Rel Res 121, *95 98*

D Souza, N , Stachiewicz J W , Miller J Ahmed, A M and Burke D L (1977) Thermal analysis of axisymmetric bone implants using *selfcuring polymethylmethacrylate*, paper no 57 3rd Ann Meeting of the Soc for Biomaterials, New Orleans Louis

Eckert E R G and Drake R M Jr (1972) Analysis of heat and mass transfer, McGraw Hill Kogakusha Tokyo

Feith, R (1975), Side effects of acrylic cement *implanted into bone* Suppl nr 161 Acta Orthop Scand

Frados, J (ed) (1966), Modern Plastics Encyclopedia 1967, Mode n Plastics vol 44 p 41

Fried E (1969), Thermal conduction contribution *to heat transfer at contacts* In Thermal conductivity, (Tye, R P ed), Acad press *London and New York*

Graf K und Stein E (1957), Fortlaufende Registrierung der Knochenmarkdurchblutung *des Menschen mit der Warmeleitsonde* Zeitschrift f die gesamte exp Medizin Bd 129 s 1 14

Grober, Erk und Grigull (1961), *Warmeubertragung*, Springer Verlag, Berlin

Henschel C J (1943) Heat impact of revolving *instruments on vital dentin tubules* J Dent Res no 22 p 323

d Hollander A Burny F Monteny E and Donkerwolcke M (1976) Extra-osseous variations of temperature during polymerization of acrylic cement in hip arthroplasties Acta Orthop Scand 47 pp 186-188
Homsy C A Tullos H S Anderson M S Differante N M and King J W (1972) Some physiological aspects of prosthesis stabilization with acrylic polymer Clin Orthop and Rel Res 83 pp 317 328
Huiskes R (1977) Warmte afvoer van zelfhardend botcement, Report no RH 77-02 Lab Exp Orthop Dept Orthop Univ of Nijmegen The Netherlands
Huiskes R de Wijn J R Slooff T J J H and van Rens Th J G (1977) Thermodynamic FEM analysis of self curing bone cements (PMMA) 1st Eur Conf on Evaluation of Biomaterials Strasbourg September (acc for publication in Advances in Biomaterials Winter and Leray eds)
Huiskes R (1978) Warming up of acrylic cement assuming non linear heat capacity properties unpublished data
Huiskes R and Slooff T J J H (1978) Temperature values in bone tissue during implantation of self curing PMMA Eur Soc of Biomaterials Brussels May
Huiskes R and de Wijn J R (1978) Heat conduction in acrylic bone cement a thermodynamic analysis 24th Ann Meeting Orthop Res Soc Dallas Tex Febr (publ Transactions J Bone Jt Surg vol 2 no 1)
Huiskes R (1979a) Thermal tissue damage by acrylic cements 25th Ann Meeting Orthop Res Soc San Francisco Cal February (to be published in Transactions J Bone Jt Surg 1979)
Huiskes R (1979b), Solution of the diffusion convection equation using FEM, Report ORa 79 05 Lab Exp Orthop Dept Orthop, Univ of Nijmegen The Netherlands
Huiskes R de Wijn J R and Slooff T J J H (1979) Heat analysis of self curing PMMA *as used in bone cements 3rd Int Conf Plastics in Med and Surg Enschede Netherlands* June
Hupfauer W und Ulatowski L (1972) Die Temperaturenentwicklung verschiedener Knochenzemente wahrend des Abhartungsvorganges Arch Orthop Unfall -Chir 72 174-184
Jacobs R B and Starr C (1939) Thermal conductance of metallic contacts Rev Scient Instrum 10 140
Jefferiss C D Lee A J C and Ling R S M (1975) Thermal aspects of self curing polymethylmethacrylate J Bone Jt Surg 57 B no 4 pp 511 518
Kaye G W C and Laby T H (1959) Tables of physical and chemical constants *and some* mathematical functions Longmann London
Kuhl P R Sheline G E and Alpen E L (1954) Blister formation and tissue temperature in radiant energy and contact burns Amer J Pathol 30 p 695
Kummer B K F (1972) Biomechanics of bone In Biomechanics its foundation and objective ’C Fung ed) Englewood Cliffe N J Prentice Hall
Labitzke ?aulus M (1974) Intraoperative Temperaturmessungen in der *Hüftchirur* g e wahrend der Polymerisation des Knochenzementes Palacos Arch Orthop Unfall Chir 79 341 346
Leach E H Peters R A and Rossiter R J (1943) Experimental thermal burns especially the moderate temperature burn Quart J Exp *Physiol* 32 67
Lee H B and *Turner* D T (1977) Temperature control of a bone cement by addition of crystalline monomer J Biomed Mat Res 11 *671 676*
Lehnartz E (1959) Chemische Physiologie *Springer Verlag* Berlin Göttingen Heidelberg.
Lundskog J (1972) Heat and *bone tissue Scand J of Plastics* and Reconstr Surg suppl 9
Meyer J R Lautenschlager E P and Moore E K (1973) On the setting properties of acrylic bone *cement* J Bone Jt Surg 55 A 149 156

Moritz, A R and Henriques, F C Jr (1947), Studies of thermal injury II, Am J Path 23, 695
Moritz, A R (1947), Studies of thermal injury III, Am J Path 23, 915
Muller, K (1975), Verhalten von Knochenzementen unter Korperahnlichen Umgebungs Bedingungen, In Die Knochenzemente (Oest *et al* eds), Ferdinand Enke Verlag, Stuttgart
Naylor, M A and Billmeyer, F W (1953), A new apparatus for rate studies applied to the photopolymerization of methylmethacrylate, J Am Chem Soc, 75, 2181 2184
Oest, O, Muller, K und Hupfauer, W (1975), Die Knochenzemente, Ferd Enke Verlag Stuttgart
Ohnsorge, J und Goebel, G (1969), Oberflachentemperaturen des abhartenden Knochen zementes Palacos beim Verankern von Metallendoprothesen im Oberschenkelmarkraum, Arch Orthop Unfall -Chir 67, 89 100
Ohnsorge J und Kroesen A (1969), Thermoelektrische Temperaturmessungen des abhar tender Knochenzementes Palacos , Z Orthop 106, 476 482
Ohnsorge, J und Goebel, G (1970), Die Verwendung unterkuhlter Metallendoprothesen in der Huftchirurgie, Z Orthop 107 683 696
Rhinelander, F W (1972), Circulation in bone, In The biochemistry and physiology of bone (Bourne G H, ed), 2nd ed vol II, Academic Press, New York
Saulgozis Y Slutskii, L I, Knets I V and Yanson, Kh A (1974), Investigation of the rela *tions between the various mechanical properties and the biochemical composition of* human bone tissue, Polymer Mechanics 9/1, 119 125
Schoofs A J G van Beukering L H Th M en Sluiter M L C (1978), Triquamesh, Progel report PRGL 1/O R 78/1, Report No WE 78 01, Dept Applied Mech Mech Eng, Eindhoven Univ of Technology The Netherlands
Seidel, H, Eggert, A und Piettsch, H (1977), Intraoperative Temperaturmessungen an der Zementknochengrenze bei TEP Implantation, Arch Orthop Unfall Chir 90 pp 251 257
Sevitt, S (1957), Burns pathology and therapeutic applications, Butterworth Cie London
Sunden, G (1967), Some aspects of longitudinal bone growth, Acta Orthop Scand Suppl No 103
Swenson, L W, Jr, *Schurman D J and Piziali R (1976)*, Thermal analysis of total hip replacements using PMMA bone cement 22nd Ann Meeting Orthop Res Soc, San Franciso, Cal, February
Trommsdorf E (1963), Polymerisate der Acrylsaure ihrer Homologe und Derivate In Chemie und Technologie der Kunststoffe (Houwelink, R und Staverman A J eds) Bd II/I Akad Verlagsges Leipzig 541 599
Vachon R I Walker F J Walker, D F and Nix G H (1967) In vivo determination of thermal conductivity of bone using the thermal comparator technique, 7th Int Conf on Med and Biol Eng Stockholm, session 37
Viidik, A (1972) Functional properties of collagenous tissues, Int Rev of Conn Tissue Res Vol VI (Hall, D A and Jackson D S eds), Academic Press, New York
Wilson, E L and Nickell R E (1966), Application of the FEM to heat conduction analyses, Nucl Eng and Des, 4 pp 276-288
Wilson, E L, Bathe, K J and Peterson, F E (1974) Finite element analysis of linear and nonlinear heat transfer, Nucl Eng and Des, 29, 110-124
Wijn, de J R (1974), Reduction of maximum temperature in the polymerization of cold and heat curing acrylic resins, J Biomed Mat Res vol 8, 421 434
Wijn, de J R (1977), Private communication
Wijn de J R, Mullem P J van Ypma J Huiskes R and Slooff, T J J H (1978) Develop ment of polymethylmethacrylate aqueous gel bone cements, parts I and II Report Cement Group, Lab Exp Orthop and Lab Dent Mat Res Univ of Nijmegen, the Netherlands
Zienkiewicz, O C (1977) The Finite Element Methods 3rd ed McGraw Hill Ltd London

SECTION THREE

STRESS ANALYSES OF
INTRAMEDULLARY FIXATION SYSTEMS

CONTENTS

CONTENTS

LIST OF SYMBOLS

In the following list of symbols, where i or j occur as indices, they either denote b (for bone), c (for cement) or s (for stem)

geometrical parameters

L_b	mm	bone length
L	mm	fixated stem length
L_f	mm	free stem length
r_s	mm	stem radius
d_s	mm	stem diameter
r_b	mm	inner bone radius
d_b	mm	inner bone diameter
r_o	mm	outer bone radius
d_o	mm	outer bone diameter
ρ	mm	ratio r_s/r_b
γ_s	mm	outer circumference of the stem
γ_b	mm	inner circumference of the bone
d	mm	stem thickness in y direction (plane model), see paragraph 5 5

reference systems

x, y, z	mm	rectangular coordinate system
r, φ, z	mm	cylindrical coordinate system
ξ	mm	coordinate in negative z direction ($\xi = L - z$), see paragraph 5 3

materials properties

E_i	N/mm²	Young's modulus
ν_i	-	Poissons s ratio

loading parameters

X	N	force on the proximal end of the free stem region in negative x direction (see fig 3 1)
Z	N	force on the proximal end of the free stem region in negative z direction (see fig 3 1)
M	Nmm	bending moment on the proximal end of the free stem region around the y axis (see fig 3 1)
$M_j(z)$	Nmm	bending moment in bone layer or stem

$M(z)$	Nmm	total bending moment in cross section ($M = M_b + M_s + M_c$)
M_L	Nmm	bending moment in the stem at $z = L$ (fig 5 8)
M_0	Nmm	bending moment in the bone at $z = 0$ (fig 5 8)
$N_i(z)$	N	normal (axial) force in bone layer or stem (positive z-direction)
$N(z)$	N	total normal force in cross-section ($N = N_b + N_s + N_c$)
N_L	N	normal force in the stem at $z = L$ (see fig 5 11)
N_0	N	normal force in the bone at $z = 0$ (fig 5 11)
$T_i(z)$	N	transverse force in bone layer or stem (positive z direction)
$T(z)$	N	total transverse force in cross section ($T = T_b + T_s + T_c$)
T_L	N	transverse force in the stem at $z = L$ (see fig 5 8)
T_0	N	transverse force in the bone at $z = 0$ (see fig 5 8)
$p_s(z)$	N/mm	continuously distributed transverse load exerted by the cement layer on the stem (fig 5 9)
$p_b(z)$	N/mm	continuously distributed transverse load exerted by the cement layer on the bone (fig 5 9)
$p(z)$	N/mm	as p_s and p_b if both are assumed equal
$q_s(z)$	N/mm	continuously distributed shearing load exerted by the cement layer on the stem (fig 5 11)
$q_b(z)$	N/mm	continuously distributed shearing load exerted by the cement layer on the bone (fig 5 11)
$q(z)$	N/mm	as q_s and q_b if both are assumed equal

displacements

$u_s(z)$	mm	deflection of the stem neutral axis in x-direction
$u_b(z)$	mm	deflection of the bone neutral axis in x-direction
$w_s(z)$	mm	displacement of the stem in z-direction
$w_b(z)$	mm	displacement of the bone in z-direction

cross sectional parameters

A_i	mm^2	cross sectional area
W_i	mm^3	moment of resistance
I_i	mm^4	second moment of inertia
P_i	N	compressional stiffness ($P_i = E_i A_i$)
F_i	Nmm^2	flexural stiffness ($F_i = E_i I_i$)
C_a	N/mm	stiffness of the cement layer against axial loading (shear)
C_t	N/mm^2	stiffness of the cement layer against transverse loading
λ_a	mm^{-1}	coefficient for axial loading
λ_t	mm^{-1}	coefficient for transverse loading

stress parameters

$\sigma_r, \sigma_t, \sigma_z$	N/mm²	direct stresses (table 3 III)
$\tau_{rt}, \tau_{rz}, \tau_{tz}$	N/mm²	shear stresses (table 3 III)
$\hat{\sigma}, \hat{\tau}$	N/mm²	stress 'amplitudes' (paragraph 5 1)
σ_1, σ_2	N/mm²	principal stresses
σ_{eq}	N/mm²	equivalent stress (chapter 3)
$s_{zi}(z)$	N/mm²	maximal axial stress (σ_z) in a cross section
$\bar{s}_{ri}(z)$	N/mm²	average normal stress in transverse direction at the stem cement interface (s) or at the cement bone interface (b) (paragraph 5 2 1)
$t_i(z)$	N/mm²	axial shear stress at the stem cement interface (s) or at the cement bone interface (b) (paragraph 5 2 2)

others

$g(\nu_c)$	–	expression in ν_c (appendix B)
c_1, c_2	–	constants (appendix B)
α, β, ϵ	–	factors (paragraph 7 1)

CHAPTER ONE

INTRODUCTION

The question as to whether a specific structure will fail or not depends on two different sets of properties First, the strength of the structure in this case of the implant the cement layer the bone and the connection between these components second the loading of the structure in a local sense, in other words the stress distribution This last depends solely on the loading of the structure (the joint loading) the geometry of the structure the constitutive properties of the materials (for instance their elasticity) and the conditions at the connections of the components (the interfaces)
The strength characteristics of the components can be evaluated by applying laboratory materials testing the stress distribution by applying stress analyses either experimental or theoretical Theoretical analyses may either be analytical in which case the stress components are directly expressed in formulas that contain the loading geometrical and materials parameters (closed form solutions) or numerical in which case the solution is not available in closed form but obtained by applying numerical (computer) procedures Regarding experimental stress analyses different methods are available (Durelli 1977) of which only a few are suitable to be used for bone prosthesis structures (e g strain gauges stress coating photo-elastic techniques)
It should be the aim of a stress analysis not only to evaluate the stress distribution in specific circumstances but also to obtain general fundamental concepts on the relation between the stresses and the loading geometrical and materials properties or in other words to find the characteristic parameters of the structure and evaluate their influences on the mechanical behavior This aim is best fulfilled by using analytical methods since in that case the characteristic parameters and variables are directly related in formulas However closed form solutions can usually only be obtained for simple structures so that often numerical methods will have to be used By applying parametric analyses in this case the influences of the structural parameters on the stresses can be evaluated empirically
Experimental methods are empirical in essence and usually have only few possibilities for parametric analyses they thus offer only limited options for acquiring fundamental and general data (Huiskes and v Heugten 1974)

To conduct a theoretical stress analysis analytical or numerical a mathematical model of the structure has to be developed which describes its mechanical behavior to an adequate degree of accuracy In the case of intramedullary bone prosthesis structures such a model is far from trivial In the first place the structure is difficult to describe mathematically owing to

- the irregular geometry of the bone
- the nonhomogeneous anisotropic and viscoelastic properties of the bone tissue
- the dynamic character of the joint loading
- locked in stresses in the cement mantle caused by dimensional changes during the polymerization process
- the complicated mechanical conditions of the cement s em and cement bone contact regions the interfaces where loosening upon tension and slip may occur

Even if a model taking these complicated properties into account can be set up it will be difficult to establish the values of the parameters that have to be used in the calculations

stress parameters

$\sigma_r, \sigma_t, \sigma_z$	N/mm²	direct stresses (table 3 III)
$\tau_{rt}, \tau_{rz}, \tau_{tz}$	N/mm²	shear stresses (table 3 III)
$\hat{\sigma}, \hat{\tau}$	N/mm²	stress 'amplitudes' (paragraph 5 1)
σ_1, σ_2	N/mm²	principal stresses
σ_{eq}	N/mm²	equivalent stress (chapter 3)
$s_{zi}(z)$	N/mm²	maximal axial stress (σ_z) in a cross section
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others

$g(\nu_c)$	–	expression in ν_c (appendix B)
c_1, c_2	–	constants (appendix B)
$\alpha, \beta\ \epsilon$	–	factors (paragraph 7 1)

CHAPTER TWO

REVIEW OF LITERATURE ON RELEVANT THEORETICAL STRESS ANALYSES

Scientists have long been interested in stresses and strains in human bones The first sophisticated stress analysis of a human bone the proximal femur was published by Meyer in 1867 This work was repeated and extended by Wolff (1870) and resulted in the well known hypothesis on the functional stress-related adaption of the bone structure Koch (1917) confirmed this hypothesis after analyzing a cadaveric femur with beam theory and promoted it to Wolff's law Beam theory was later used for stress analyses of the human femur by Toridis (1969) this time taking three-dimensional loading and geometry into account by Rybicki *et al* (1972) who compared the results with more sophisticated stress analyses methods (Finite Elements) and by Scholten (1975) who took three dimensional geometry and non *homogeneous* material properties into account and also applied Finite Element Methods Although frequently used it has not been verified whether the assumptions of linear elastic beam theory apply to the mechanical behavior of the femur a problem investigated in our group and which will be discussed briefly in chapter 4

As in other areas of solid mechanics biomechanics research has greatly benifited from the *introduction* of Finite Element Methods (FEM) a computer-oriented method for stress analyses eminently suitable for arbitrarily shaped structures with arbitrary loading and materials properties (e g Zienkiewicz 1977) This method was introduced into the *orthopedic biomechanics* field as an expedient for structural analyses of bone by Brekelmans *et al* (1972) and Rybicki *et al* (1972) simultaneously Both presented relatively simple plane stress models of the femur FEM models developed in later years by other investigators became more refined especially in their geometrical aspects With few exceptions all concerned the femur

Wood *et al* (1973 1975) presented a plane stress model of the proximal femur taking non uniform thickness into account Olofsson (1975 1976) analyzed a truly three dimensional FEM model of the intact femur The problems of data manipulation interpretation and representation that are still connected with such complex models are reflected in his work His calculations took up huge amounts of computer time leaving few possibilities for parametric analyses.

Quite refined and accurate two-dimensional and three dimensional FEM models of the proximal femur were developed by Scholten (1975) Geometry and elastic properties (non homogeneous) were exclusively measured for these calculations The results were compared with beam models an example of which is shown in fig 2 1

A somewhat less refined three-dimensional model was reported by Valliapan *et al* (1977) They varied the joint loading and compared the results with a two-dimensional analysis a beam analysis and an experimental strain analysis Agreement was good in the relative sense but poor in the absolute sense especially in the proximal medial region which they attributed to discrepancies between the modeled and real bone-geometrical and material properties. A three dimensional anisotropic FEM analysis of the femur was carried out by Vichnin and Batterman (1977) who used geometrical data measured by Laaper (1973a)

Harris *et al* (1978) too analyzed a three-dimensional model of the proximal femur and compared the results with a two-dimensional and a beam model agreements appear to be reasonable

Moreover, the relations between such a refined model and the real structure will be badly defined because
- bone geometry, bone material properties and loading characteristics vary considerably from patient to patient,
- the mechanical characteristics of the bone prosthesis structure depend on the surgical procedure which may vary to a great extent,
- the bone geometry, the bone material properties and the interface conditions may undergo gradual postoperative change due to bone remodeling

Altogether, a detailed accurate theoretical analysis of the mechanical behavior of specific bone prosthesis structures is an unrealistic goal as yet However, general, fundamental concepts of the influences of the essential characteristics of such a structure can be obtained and tendencies can be studied by analyzing simplified models using both analytical and numerical methods, as will be shown in this section

A survey of the literature on previous work is given in the following chapter

In the third chapter a simplified (general) model of intramedullary fixation systems is intro duced This model is analyzed using different methods, as described in chapter 5 The ana lyses provide the essential characteristics of the bone prosthesis structure and a number of simple formulas to approximate the most important stress values in the stem, the cement and the bone A simple and rapid numerical evaluation method for specific stem designs and their expected mechanical performance in a given bone will also be developed

Results of an experimental stress analysis, that serve as references for the theoretical results will be briefly discussed in the fourth chapter

The theoretical model is an abstraction of the real system, of which many complicated aspects are neglected The possible influences of these aspects are discussed in chapter 6

In the last chapters some guidelines will be given for implant designs and implantation procedures as derived from the analyses Due to the fact that the hip joint is by far the one most often replaced and that most data available concern the proximal femur the following analyses are focussed on hip endoprostheses It should be kept in mind, however, that the methods and some of the results can be generalized to apply to other intramedullary fixated artificial joints as well

A simplified axisymmetric model of an intramedullary fixation system using three dimensional FEM and composite beam theory was analyzed by Bartel and Ulsoy (1975) Bartel and Samehyek (1976) Bartel and Desormeaux (1976a 1976b) Thanks to a reduction in the number of geometrical parameters these studies resulted in a more general comprehension of the mechanical behavior than did other more complicated studies

Andriacchi *et al* (1975) used a plane stress FEM analysis to study the proximal femur with different kinds of prostheses implanted in neutral varus and valgus positions Since in their model there was no connection between the medial and the lateral cortex they in fact analyzed a kind of sandwich construction that can hardly be expected to be a reliable representation of the real system as will be discussed in paragraph 5 5

The same method was applied by Kwak *et al* (1979) who studied the influences of the cement layer thickness in a two dimensional FEM model of the proximal femur with an implanted Charnley prosthesis

A better method was presented by Hampton *et al* (1976) who analyzed a comparable plane stress model but took the full stiffness properties of the femur into account by modeling a side plate or spanning-element layer between the medial and the lateral cortex They also developed a three dimensional FEM model of the same structure

Svensson *et al* (1977) presented a two-dimensional FEM model taking three-dimensional geometry into account and also using spanning element layers to model the medial lateral bone connection They found a reasonable qualitative agreement between the calculated stresses at the bone surface and results of stress-coating experiments carried out by Brockhurst (1975) They simulated different stem designs and elastic layer properties and concluded that by using a thick stem most of the critical stresses will be reduced They were the first to investigate the influences of the interface conditions In one calculation they assumed the stem cement connection as allowing slip and no tension and found a completely different stress distribution at the interfaces compared to the results of calculations in which the materials were assumed to be rigidly connected

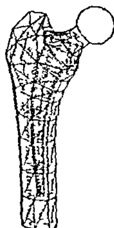


fig 2 2 Element mesh of a three-dimensional FEM model of the proximal femur with implanted hip prosthesis This and comparable models analyzed by Rohrle et al (1977 1979) and Scholten et al (1978) are the most detailed ones in the present literature with respect to geometrical and material representation (reproduced with permission of Rohrle et al 1979)

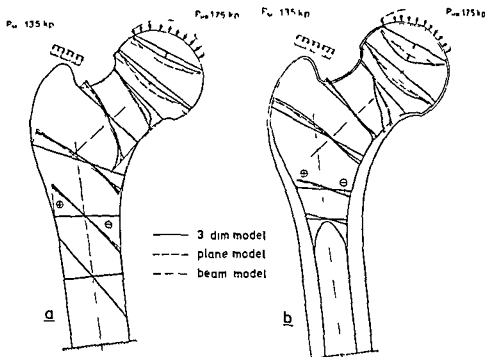


fig 2 1 Comparison of a three dimensional FEM model, a two dimensional FEM model and a beam model of the proximal femur Axial direct stresses in the cortex (a) and in the spongeous bone (b) are shown The plane shown is a plane of symmetry in the three models Up to the neck region the agreement is rather good (reproduced with permission of Scholten, 1975)

With the object of verifying certain assumptions in the process of modeling, Rohlmann *et al* (1977, 1978) analyzed a longitudinal slice of the femur, using FEM and strain gauges They also analyzed a three dimensional model with FEM (Rohlmann *et al*, 1979), the results of which they compared with those of strain gauge experiments on a cadaveric femur They found poor agreement in the absolute sense and concluded that in a FEM model a quite refined element mesh should be used, the boundaries between spongeous and cortical bone should be accurately evaluated and modeled and the exact ratio of stiffness properties should be taken into account
Apart from the femur the tibia has received some attention in structural analysis Chand *et al* (1976) published a two dimensional FEM analysis of the knee joint and Hayes *et al* (1978) reported a three dimensional analysis of an axisymmetric model of the proximal tibia The full tibia was analyzed by Piziali *et al* (1976) and by Minns *et al* (1977)

In the meantime theoretical stress analyses of bone prosthesis structures were published again usually on the femoral part of the hip joint A plane stress FEM model of the proximal femur with three different types of prostheses was reported by McNeice *et al* (1975) and McNeice and Amstutz (1976) Based on their studies they defined 4 different failure modes for cement fracture which they later used to evaluate results of total hip replacements radiographically (McNeice and Gruen, 1976, Gruen and Amstutz 1977) Their model will be discussed further in paragraph 5 5
Forte (1975) carried out a FEM beam analysis of a prosthesis stem with the object of optimizing its shape, a quite unrealistic model, since the important mechanical interaction with the bone was completely ignored

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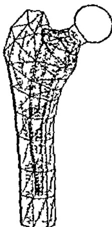


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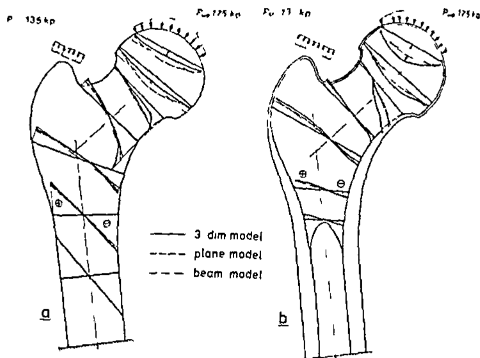


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Because of the many complicated features of bone prosthesis structures and the usually uncertain numerical values of parameters one cannot expect to be able to develop a mathematical model that will predict the stress distribution in the real structure in an absolute sense This fact is recognized by most of the authors previously cited and it is often remarked that because of the possibilities for parametric analyses in the models they can still contribute to a better comprehension of the mechanical behavior Although this is true in general the overall picture of the work previously discussed is rather confusing This is due to the fact that many of the complex models used are rather specific and little is known about the influences of simplifying assumptions this often places the analysis procedures in a frame of numerical empiricism (Oden and Bathe 1978) and results in anything but general concepts Hence the results of the analyses are sometimes in conflict and are usually quite specific To acquire more general data a model should be relatively simple with options for either extensive parametric analysis or closed form solutions Therefore detailed three-dimensional FEM models are not very suitable to fulfil this aim due to their complexity and also at least contemporarily to the excessive computer time and data manipulation efforts needed thus limiting the possibilities for extensive parameter variation Moreover it appears to be rather illogical to use a model that is quite refined in its geometrical aspects while rough in the other aspects such as those summarized in chapter 1

In short it is evident that although many significant contributions to insight in the mechanical behavior of intramedullary bone prosthesis structures have been presented in the literature there is a need for more general and fundamental concepts on the relations between structural parameters and mechanical performance It was the object of the work presented in this section to find the essential characteristics of the structure and to provide such concepts

Probably the most detailed FEM analyses of the proximal femur with implanted prostheses were carried out by Rohrle *et al* (1977, 1979) and Scholten *et al* (1978) Their models were truly three dimensional, using adequately refined element meshes (fig 2 2), non homogeneous bone properties were taken into account as well as three dimensional loading Interfaces were modeled as either allowing or not allowing slip and otherwise rigidly connected These models were used in comparative studies to evaluate specific designs and to answer specific questions with respect to design features as, for Instance the influences of calcar support or the stiffness of the intermediate layer
Another three dimensional FEM analysis of the proximal femur with an implanted hip prosthesis was reported by Crowninshield *et al* (1979), who had earlier analyzed the influences of cross sectional stem shapes (Crowninshield and Branch, 1978) They carried out parametric analyses, varying Young s moduli of stem and cement, stem thickness and stem length Based on their results they advocate a decrease of cement stiffness and an increase of stem length thickness and stiffness in order to decrease the cement stresses Their calculations were compared to simple strain gauge experiments resulting in qualitative ly reasonable agreement for femoral surface stresses In their model the different materials were assumed to be rigidly connected at the interfaces
A detailed three dimensional FEM analysis was reported by Tarr *et al* (1979) In a model using a rather coarse element mesh a cobalt chromium and a more flexible titanium alloy stem were simulated They found that stresses in the stem and in the distal cement layer were lower with the titanium alloy, while stresses in the proximal cement layer were higher Comparison of results with a simple strain gauge experiment on a cadaveric femur gave poor absolute but reasonable qualitative agreement

An interesting venture was undertaken by Rohlmann *et al* (1979), who analyzed a model of a hip endoprosthesis cemented into a brass tube, using three dimensional FEM (a model with 1600 degrees of freedom) and also strain gauge experiments They found rather poor continuity of stresses at the interfaces in the calculations and only moderate agreement between experimental and theoretical results, both of which they ascribed to the coarseness of the element mesh, indicating that in the three dimensional FEM models quite a high level of mesh refinement is needed
Another approach to structural analysis of intramedullary fixation systems was followed by an Italian group (Calderale *et al*, 1977, Barberi *et al*, 1978, Gola and Gugliotta, 1979), who modeled the femur and the prosthesis stem as cantilever beams coupled by an elastic (cement) layer The model was analyzed numerically using minimal potential energy criteria The model can be applied for transverse loading only The stiffness of the elastic layer was evaluated experimentally Although the information resulting from analyses of this kind is limited they are quite simple and can conveniently be used for a first-order rapid evaluation of stem designs

Where intramedullary fixation is concerned, few efforts have been put into sophisticated theoretical analyses of other than hip endoprostheses Van Campen *et al* (1978 1979) reported two and three dimensional FEM analyses of the tibial stem fixation of a hinged artificial knee joint, comparing the results with strain gauge experiments A three-dimensional FEM analysis of a new intramedullary fixation system for artificial finger joints was carried out in our group (Huiskes and v Heck 1978, Huiskes *et al*, 1979)
Theoretical stress analyses of other than intramedullary fixated prostheses at least not mainly fixated in this manner have been carried out for tibial components of artificial knee joints (Chao *et al* 1977 Lewis 1977, Askew *et al*, 1978 1979 Hayes 1978) and for the hip surface replacement (v Heck and Huiskes 1979)

parameter	symbol	unit	value	parameter	symbol	unit	value
bone length	L_b	mm	205	stem cross sectional area	A_s	mm^2	78 5
cemented stem length	L	mm	80	stem second moment of inertia	I_s	mm^4	490 1
free stem length	L_f	mm	25	bone cross-sectional area	A_b	mm^2	392 7
stem radius	r_s	mm	5	bone second moment of inertia	I_b	mm^4	31 906 8
inner bone radius	r_b	mm	10				
outer bone radius	r_o	mm	15				

table 3 I Reference values for geometrical and some mechanical parameters in the axi symmetric (constant cross section) model

parameter	symbol (1)	unit	bone (cortical) (2)	stem (steel)	cement
Young s modulus	E	N/mm^2	2×10^4	2×10^5	2×10^3
Poisson s ratio	ν	–	0 33	0 33	0 33

table 3 II Reference values for the materials properties (1) subscripts b, s and c refer to bone stem and cement respectively (2) e g Evans (1973)

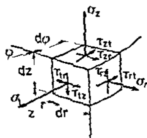


fig 3 2 The nine components of the stress tensor in a cylindrical coordinate system (r φ z)

The state of stress at a point of the structure is described by the three dimensional stress tensor in a cylindrical coordinate system (r φ z) as shown in fig 3 2 The stress components are described in table 3 III Due to the action = reaction law some stress components have to be continuous across the stem cement and cement bone interfaces in this model these components are σ_r, τ_{rt} and τ_{rz}

Due to compatibility requirements and differences in elastic moduli of the materials the other stress components have to be discontinuous across the interfaces In order to be able to judge the stress state at a point of the structure or simply to reduce the amount of data describing the stress state an equivalent stress based on a certain failure criterion can be

CHAPTER THREE

A SIMPLIFIED MODEL OF INTRAMEDULLARY FIXATION STRUCTURES

The model is shown in fig 3 1 It consists of an axisymmetric bone' with an axisymmetric intramedullary stem Both the stem and the bone have constant cross sectional properties

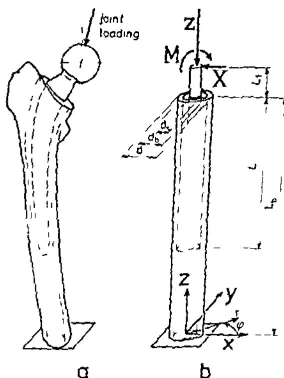


fig 3 1 The axisymmetric model (b) of an implanted hip endoprosthesis (a) geometrical parameters coordinate systems and loading are shown

Between the stem and the bone a layer of acrylic cement rigidly connected to both the stem and the bone is assumed Although the model can be regarded as a general one for any intramedullary fixation structure the dimensions were chosen according to the hip endoprosthesis as more-or less average as reported in the literature (Kempf *et al* 1976, Laaper, 1973a Huiskes and Slooff 1979b) Although dimensions will be varied in the calculations, a set of what will be referred to as reference values is shown in table 3 1
The stem layer and bone materials are assumed as behaving linear elastic isotropic and homogeneous Values for Young s moduli and Poisson s ratios were chosen as more or less average values of those presented in the literature (table 3 1), see also section 1)
A three dimensional state of loading on the stem is assumed represented by an axial force (Z), a transverse force (X) and a bending moment (M) The stress analyses are carried out for each of these loading cases separately Since the stresses and deformations in the structure, because of the linear assumptions, are proportional to the load magnitudes these were chosen arbitrarily as 1 000 N 100 N and 10 000 Nmm respectively

CHAPTER FOUR

AN EXPERIMENTAL STRESS ANALYSIS OF A CADAVERIC FEMUR WITH IMPLANTS

Apart from theoretical stress analyses as reviewed in chapter 2 also experimental stress and strain analyses of bones both intact and provided with implants have been reported Brittle coating photo elastic, optical and strain gauge techniques have been used Many strain gauge experiments concerning intramedullary fixation structures have been reported recently devoted with few exceptions (e g v Campen *et al* 1978 1979) to the proximal femur with hip endoprostheses
The first experiments of this kind were carried out in our group (Slooff 1970 1971 Brekelmans en Poort 1973 v Heugten 1974 Huiskes *et al* 1976 Huiskes 1978 Huiskes and Slooff 1979b) Strains were measured on the outside surface of the loaded femur intact as well as provided with implants Comparable experiments were conducted by Oh and Harris (1978) who applied only a few strain gauges but carried out measurements on different bones with different prostheses by Huggler *et al* (1978) who also attached strain gauges to the prosthesis stem and by McBeath *et al* (1979) As discussed in chapter 2 more of these experiments have been carried out specifically to verify theoretical results

The experiments conducted by our group concerned the cadaveric femur of a 52 yr-old man To the femur kept in formaline 112 rosette strain gauges were attached (fig 4 1 a) Forces on the head in 3 perpendicular directions and couples in 3 planes were applied separately in turn (fig 4 1 b)
To calculate the measured strain values (three for each strain gauge) to principal stresses linear elasticity homogeneity and isotropy was assumed the bone Young s modulus was taken as 20 000 N/mm^2 and its Poisson s ratio as 0 37
Equivalent stresses were calculated using the maximal deformational energy criterion of Maxwell Huber Hencky Von Mises It should be noted that with such an experimental method the complete strain distribution in the structure can *not be measured* but only the strain state at the outside surface The stresses calculated from the experimental data were compared to the corresponding values of stresses as calculated for the model in this case σ_t σ_z and $\tau_{zt} = \tau_{tz}$ at the outside surface of the bone
It was found that in loading by pure couples (up to 12 500 Nmm) the bone showed linear elastic behavior loading by axial force (up to 1 000 N) resulted in nonlinear behavior This indicates material linearity and geometrical nonlinearity which means that due to the bending of the bone an additional couple is introduced that increases with the applied load Some viscoelastic behavior occurred however after 3½ min of constant loading the strains stabilized to constant values. The reproduceability of the strain measurements was better than 5% even after 2½ years

The measurements were repeated for the same femur applied with prostheses Kuntscher nails of three different diameters hip endoprostheses fixated with and without cement with short and long stems and osteosynthesis plates screwed to the bone For the present study only the results referring to the intact femur and the femur applied with a short and a long cemented Mueller prosthesis (fig 4 1 c) are relevant An example of these results is shown in fig 4 2 It is evident that the stress state at the outside surface of the proximal femur is influenced by the presence of the stem the stresses are considerably lower if a

stress component	names used	stress component	names used
σ_r	radial stress, transverse stress	$\tau_{rt} = \tau_{tr}$	tangential shear stress circumferential shear stress
σ_t	tangential stress, circumferential stress, hoop stress	$\tau_{rz} = \tau_{zr}$	axial shear stress, longitudinal shear stress
σ_z	axial stress, bending stress	$\tau_{zt} = \tau_{tz}$	transverse shear stress

table 3 III The six independent stress components of the stress tensor and their terminology

calculated from the six independent stress components Here the maximal deformational energy criterion is used, according to Maxwell Huber Hencky Von Mises

$$\sigma_{eq} = \sqrt{[\{ (\sigma_r-\sigma_t)^2 + (\sigma_r-\sigma_z)^2 + (\sigma_t-\sigma_z)^2 \} /2 + 3(\tau_{rt}^2 + \tau_{rz}^2 + \tau_{tz}^2)]}$$

It should be remarked here that his equivalent stress has proven its value as a yield crite rion for such materials as stainless steel Although it will probably give an indication of the stress state in cement or bone, its value as a yield criterion for these materials is uncertain

The model presented here will be analyzed using different analytical as well as numerical methods (FEM), as described in chapter 5
It cannot be expected that with such a simplified model the stress distribution in the real structure can be predicted accurately in an absolute sense, which is obviously not the object of the investigation It is expected on the other hand, that the structure is described by the model in a qualitative sense In order to roughly verify this expectation, the calculated results are compared to results of strain gauge experiments that will be discussed briefly in the next chapter In chapter 6 the influences of system parameters that are neglected in this simplified model (thermal stresses, interface loosening, nonconstant cross sectional properties of the structure the occurrence of torsional loading and a few others) will be evaluated or at least discussed

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The first experiments of this kind were carried out in our group (Slooff 1970 1971 Brekelmans en Poort 1973 v Heugten 1974 Huiskes *et al*, 1976 Huiskes 1978 Huiskes and Slooff 1979b) Strains were measured on the outside surface of the loaded femur intact as well as provided with implants Comparable experiments were conducted by Oh and Harris (1978) who applied only a few strain gauges but carried out measurements on different bones with different prostheses by Huggler *et al* (1978) who also attached strain gauges to the prosthesis stem and by McBeath *et al* (1979) As discussed in chapter 2 more of these experiments have been carried out specifically to verify theoretical results

The experiments conducted by our group concerned the cadaveric femur of a 52 yr-old man To the femur kept in formaline 112 rosette strain gauges were attached (fig 4 1 a) Forces on the head in 3 perpendicular directions and couples in 3 planes were applied separately in turn (fig 4 1 b)
To calculate the measured strain values (three for each strain gauge) to principal stresses linear elasticity homogeneity and isotropy was assumed the bone Young s modulus was taken as 20 000 N/mm² and its Poisson s ratio as 0 37
Equivalent stresses were calculated using the maximal deformational energy criterion of Maxwell Huber Hencky Von Mises It should be noted that with such an experimental method the complete strain distribution in the structure can not be measured but only the strain state at the outside surface The stresses calculated from the experimental data were compared to the corresponding values of stresses as calculated for the model in this case σ_t σ_z and $\tau_{zt} = \tau_{tz}$ at the outside surface of the bone
It was found that in loading by pure couples (up to 12 500 Nmm) the bone showed linear elastic behavior loading by axial force (up to 1 000 N) resulted in nonlinear behavior This indicates material linearity and geometrical nonlinearity which means that due to the bending of the bone an additional couple is introduced that increases with the applied load Some viscoelastic behavior occurred however after 3½ min of constant loading the strains stabilized to constant values. The reproduceability of the strain measurements was better than 5% even after 2½ years

The measurements were repeated for the same femur applied with prostheses Kuntscher nails of three different diameters hip endoprostheses fixated with and without cement with short and long stems and osteosynthesis plates screwed to the bone For the present study only the results referring to the intact femur and the femur applied with a short and a long cemented Mueller prosthesis (fig 4 1 c) are relevant An example of these results is shown in fig 4 2 It is evident that the stress state at the outside surface of the proximal femur is influenced by the presence of the stem the stresses are considerably lower if a

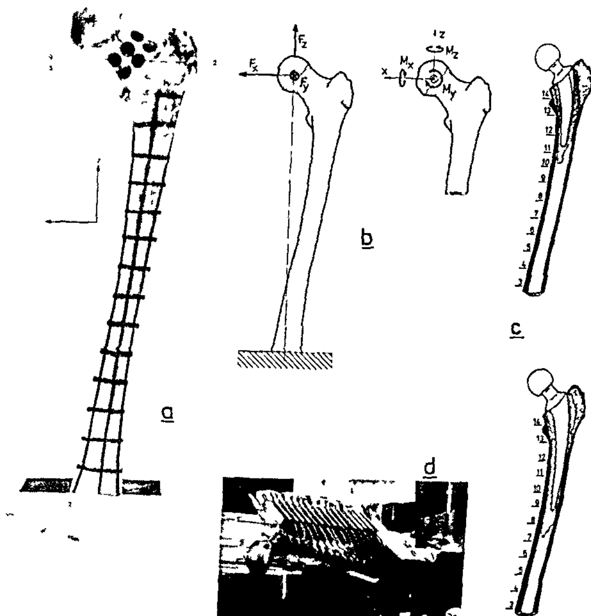


fig 4 1 Experimental stress analysis of a cadaveric femur Strain gauges were attached at the crossings of the black lines (a), forces in 3 directions and moments in 3 planes were applied to the head (b), measurements were performed on the intact femur as well as on the femur applied with hip prostheses (c), (d) shows the laboratory setting

prosthesis stem is present because part of the loading is taken up by the stem According to Saint Venant s principle there is no influence on the distal side of the bone hence the strains should be practically equal for the three cases in this region The graphs in fig 4 2 will later be compared with results of the model calculations

The experiments were carried out on the left femur of the cadaver the right femur was used for detailed measurements of the cross sectional geometry (Laaper 1973a)

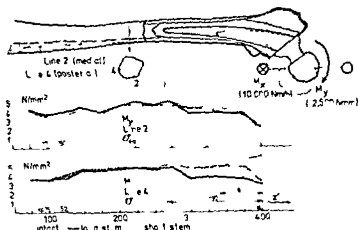


fig 4 2 Equivalent stresses at the outside surface of the femur intact and with two endo prostheses of different lengths loaded with two bending couples in different planes respectively Top graph σ_{eq} on line 2 on loading with M_y, bottom graph σ_{eq} on line 4 on loading with M_x. The stresses were calculated from the measured strains assuming homogeneity isotropy and linear elasticity ($E = 20\,000\ N/mm^2$, $\nu = 0\ 37$)

The data from these measurements were used for a three dimensional beam theory analysis of the femur (Laaper 1973b v Heugten 1975 Huiskes and Slooff 1979b) A comparison of beam theory results and strain gauge results principal stresses at different locations on loading with a couple in the frontal plane is shown in fig 4 3
These results indicate that at least the intact femur behaves approximately in accordance with linear beam theory (which was also found by Scholten (1975) on comparing a beam analysis with a three dimensional FEM analysis (fig 2 1)) apart from the mentioned geometrical nonlinearity on loading with forces especially in the z-direction
It should be remarked here that the Young s modulus is only used to calculate measured strains to stresses The agreement with the beam analysis thus indicates a good choice of the value of this parameter
It is remarkable regarding figs 4 2 and 4 3 that although the femur s wider on the proximal side the strain values over the length of the bone are roughly speaking more or less constant This indicates that the flexural stiffness of the bone would be fairly constant due to the higher flexibility of the bone material (spongeous bone) at the proximal side

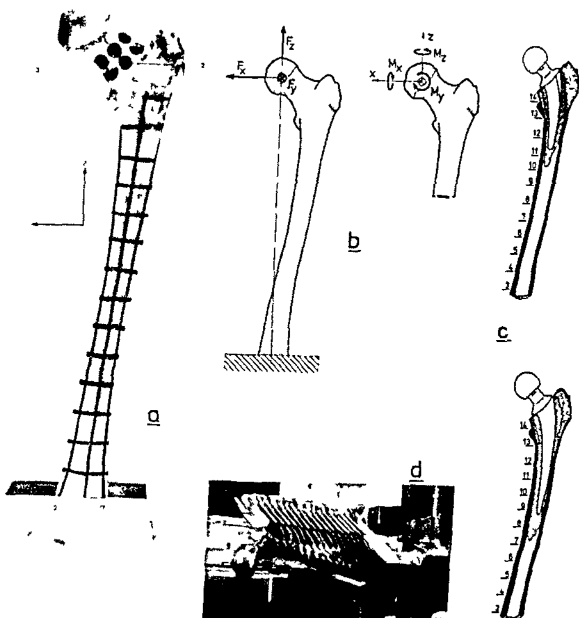


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CHAPTER FIVE

THEORETICAL STRESS ANALYSES

In this chapter a three-dimensional FEM analysis of the model presented in chapter 3 will be discussed The results of this analysis serve as references for the development of more simplified analytical descriptions of the model that are better suited to characterize its mechanical behavior in principle
In paragraph 5 4 a FEM beam model of the structure will be presented This last model and the analytical models too are based on beams on-elastic foundation theory, in which it is assumed that the stem and the bone separately behave in accordance with linear beam theory while the cement mantle serves as an elastic layer This in contradiction to composite beam theory sometimes applied in the literature in which it is assumed that the structure as an entity behaves according to beam theory
In the last paragraph of this chapter the possibilities and limitations of plane FEM analyses will be discussed

5 1 Three-dimensional FEM analysis

For the FEM analysis of the model an axisymmetric ring element is used that can take nonaxisymmetric loading into account by expansion of loads displacements, strains and stresses into Fourier series (Fourier element) The complete solution can be obtained as a superposition of the term by term solutions (Wilson 1965 v Campen 1970 Zienkiewicz 1977) The structure is divided into approximately 750 ring elements (1900 nodal points 5700 degrees of freedom) as shown in fig 5 1 Also other elements and element meshes were applied as discussed in Huiskes *et al* (1977)

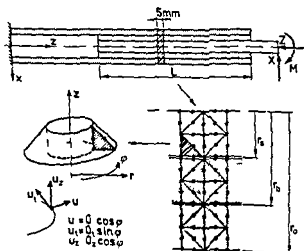


fig 5 1 Element mesh and ring element used in the three-dimensional FEM calculations

fig 4 3 *Principal stresses (σ_1) on the outside of the femur, as calculated from strain-gauge measurements (left cadaveric femur) and as calculated with beam theory using cross sectional geometry data The beam analysis did not extend further proximally than location f The principal stress direction is with good approximation, in that of the femoral axis For the calculation of principal stresses from principal strains in the strain gauge experiments homogeneity isotropy and linear elasticity was assumed Loading with a couple of M_y = -12,500 Nmm resulted in strain values opposite in sign but practically equal in the absolute sense*

- The element used is triangular in cross section and has 6 nodal points In each element the stress amplitudes are linear in r and z
- The calculations have been carried out using the FEM computer system FEMSYS (Banens 1977) The accuracy of the results has been checked using analytical considerations (Huiskes 1977)

Results

All stress component amplitudes at all nodal points were calculated for the three loading cases. From these amplitudes the stresses for any value of φ can be evaluated using the expressions shown in table 5 1 and the equivalent stress can be calculated using the formula presented in chapter 3 In the present work the stress distribution as a function of φ and r (presented in Huiskes 1977 and Huiskes *et al* 1977) will not be discussed As a rule stress amplitudes as a function of z on four different lines will be presented in the stem (line 1) and in the cement (line 2) at the stem cement interface ($r = r_s$) and in the cement (line 3) and in the bone (line 4) at the cement-bone interface ($r = r_b$)

Fig. 5 3 gives *an example of stress* (σ_{eq}) *as a function of z on the four lines just mentioned* resulting from the transverse force X A set of all relevant results for loading cases Z and X is shown in appendix A

When the results of the FEM calculations are compared with those of the experimental stress analysis of the cadaveric femur with implants discussed in chapter 4 no detailed agreement can be expected owing to the simplified character of the model

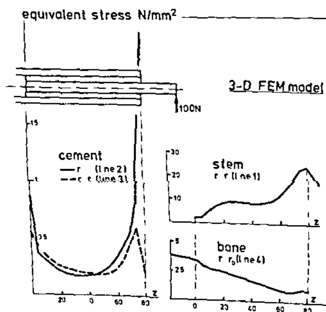


fig 5 3 Equivalent stresses in the stem (at line 1) the bone (at line 4) and the cement (at lines 2 and 3) as functions of z for a transverse force of 100 N on the stem

The loads (Z, X and M) are expanded into Fourier series, but only the first term of each series is used Hence the loads are assumed to be distributed along a nodal ring (fig 5 2) and Z, X and M are the respective resultants of these distributions This greatly economizes the solution procedure, while the effects of the assumed loading on the structure are equal to those of concentrated loading thanks to the relatively large free stem length to which Saint Venant s principle applies

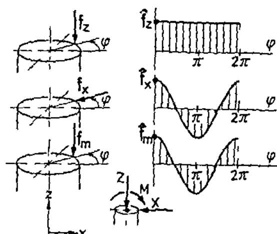


fig 5 2 The forces and the moment on the stem are assumed to be distributed along a nodal ring, either as constant or as sine or cosine functions in φ $f_z = \hat{f}_z$, $f_x = \hat{f}_x \cos\varphi$ and $f_m = \hat{f}_m \cos\varphi$, the resultants of which are Z, X and M, respectively

In consequence of this method the stresses strains and displacements that result from the axial loading (Z) are constant in φ and those that result from the transverse loading (X and M) are sine or cosine functions in φ For the stresses these functions are summarized in table 5 1

The quantities $\hat{\sigma}_r$ $\hat{\sigma}_t$, $\hat{\tau}_{rt}$ etc will be referred to as stress amplitudes, it should be borne in mind that the term in this case does not refer to dynamic loading It is evident that the stress amplitude values are equal to the maximum stress values on a nodal ring, for τ_{rt} and τ_{tz} at $\varphi = \pi/2$, for the other components at $\varphi = 0$

stress component		axial loading (Z)	transverse loading (X, M)
radial stress	σ_r	$\sigma_r(r\ z)$	$\hat{\sigma}_r(r\ z)\cos\varphi$
hoop stress	σ_t	$\sigma_t(r\ z)$	$\hat{\sigma}_t(r\ z)\cos\varphi$
axial stress	σ_z	$\sigma_z(r\ z)$	$\hat{\sigma}_z(r\ z)\cos\varphi$
circumferential shear stress	τ_{rt}	0	$\hat{\tau}_{rt}(r\ z)\sin\varphi$
longitudinal shear stress	τ_{rz}	$\tau_{rz}(r\ z)$	$\hat{\tau}_{rz}(r\ z)\cos\varphi$
transverse shear stress	τ_{tz}	0	$\hat{\tau}_{tz}(r\ z)\sin\varphi$

table 5 1 Expressions for the six stress components in axial and in transverse loading

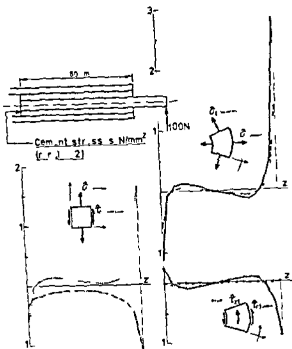


fig 5 6 Stresses in the cement at the stem-cement interface on loading with a transverse force Apart from τ_{zt} the components are of comparable magnitude indicating that the stress state in the cement is truly three-dimensional σ_r shows the highest value

- The stress state in the cement is truly three-dimensional which means that the stress components have comparable magnitudes (fig 5 6) The highest stresses in the cement occur near the stem cement interface on the proximal and distal sides for all stress components and for all loading cases Of the six components σ_r shows the highest values at these locations.
  If σ_{eq} is used as a criterion for the stress state then σ_r gives a good indication of its maximum value and τ_{rz} gives a good indication of its course as a function of z
  Although the stress distributions differ for the transverse force and the bending moment the results in principle give the same kind of information hence for a principle characterization it would be sufficient to consider only one of these loading cases Here the transverse force was chosen as the representative loading case
- As mentioned in chapter 3 the stress components σ_r τ_{rt} and τ_{rz} have to be continuous across the interface due to the action = reaction law In the calculated results this requirement was fulfilled with quite reasonable accuracy (Huiskes 1977)
- As is shown for instance in fig 5 6 the cement stress components show high stress concentrations at both ends Where τ_{rz} is concerned the stress should after a steep rise decrease sharply to zero at the ends That this is not described by the model is due to an inadequately refined element mesh in these regions
  To describe this end-effect (that also occurs in so called shear lag problems e g Timoshenko and Goodier 1970) a very refined mesh would be needed
  The stress values found for τ_{rz} at the ends are assumed to be reasonable representations

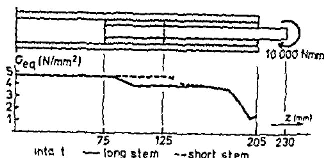


fig 5 4 Equivalent stresses at the outside surface of the bone cylinder, for two different stem lengths (80 and 130 mm) and the bone without stem, on loading with a pure couple To be compared with experimental results shown in fig 4 2

A qualitative agreement was clearly established, however as is illustrated in fig 5 4, showing equivalent stresses on the outside surface of the bone cylinder as calculated for the 'intact case and with implants of two different lengths on loading with a bending moment Comparison of these graphs with fig 4 2 makes it apparent that the model results and the experimental results agree in the qualitative sense

As regards the calculated stress distribution in general the following conclusions can be reached

- Relative to the axial stress (σ_z) all other stress components in the stem have insignificant values for all loads Hence, the equivalent stress is practically equal to the axial stress This indicates also that the stem behaves in accordance with beam theory, which is hardly surprising
- This is also true although to a lesser extent for the bone On the proximal side stress components other than the axial one have significant values also This means that apart from the proximal side, the equivalent stress is almost equal to σ_z, as shown in fig 5 5

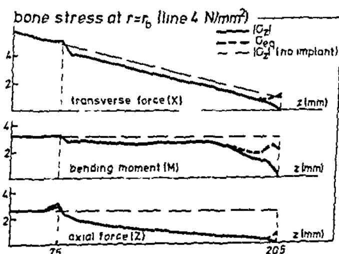


fig 5 5 Axial stress (σ_z) and equivalent stress (σ_{eq}) in the bone at line 4 ($r = r_b$) as functions of z, for three loading cases Only on the proximal side do they differ The natural axial stress for the bone without implant is also shown Especially the axial force results in low stress values as compared with the intact bone (stem length 130 mm)

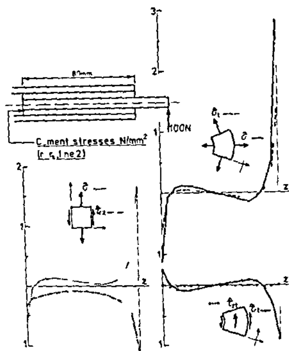


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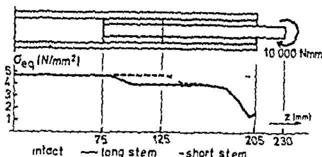


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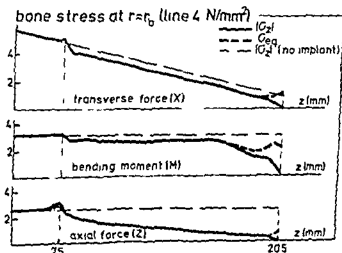


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5 2 Beams-on-elastic foundation theory

As will be shown in this paragraph the mechanical behavior of the model can be approximated by applying beams-on-elastic foundation theory, for transverse as well as for axial loading Both cases will be treated separately

5 2 1 *Transverse loading*

The theory of beams-on-elastic foundation has been described in depth by Hetényi (1946) The difference in this case from the usual one is caused by the circumstance that both beams (the stem and the bone) make a contribution to each other s elastic foundation It is assumed that both the stem and the bone behave in accordance with beam theory The resistance of the intermediate layer (the cement mantle) to shear and axial loading is neglected in this case and its transverse stiffness is taken into account by assuming a continuous set of linear springs (Winkler hypothesis Hetenyi 1946)

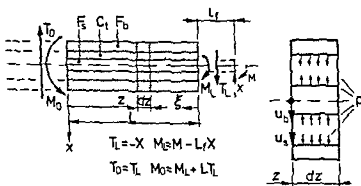


fig 5 8 Parameters and variables of the beams-on-elastic foundation model for transverse loading The external loads in this model can easily be calculated from the previously defined loading system (M and X) as shown in the figure

The parameters of the model are shown in fig 5 8 The transverse stiffness of the elastic layer C_t (N/mm^2) is defined by

$$p = C_t(u_s \quad u_b) \qquad (5\ 1)$$

where $u_s(z)$ and $u_b(z)$ are the deflections of the stem and the bone neutral axes respectively and $p(z)$ (N/mm) is the continuously distributed transverse load that the cement exerts on the stem and vice versa and that the cement exerts on the bone and vice versa
As follows directly from beam theory

$$F_s \frac{d^4 u_s}{dz^4} + p = 0 \quad \text{and} \quad F_b \frac{d^4 u_b}{dz^4} - p = 0 \qquad (5\ 2)$$

of the maximal values that will in reality occur somewhat away from the ends In this respect shear stress measurements were carried out by Stern (1977) in an axisymmetric structure consisting of an aluminium tube and a steel rod with acrylic cement in between, *under axial loading, using optic stress films He found the same kind of curves as calcu*lated with the model

It is apparent when looking at the stress distribution in the structure (figs 5 3 through 5 6 and appendix A), that the fixation system can be divided into three regions (fig 5 7) a middle region, where the structure behaves as a composite beam, which means that the stem and the bone each take a part of the total load depending on the ratio of their flexural and compressional stiffness, a proximal region where the load is passed from the stem to the bone and a distal region where, looking from the other side, the load is passed from the bone to the stem As will be shown in paragraph 5 3, these regions can be treated separately and approximative formulas can be derived to describe the most important stress components in these regions as functions of the structural parameters These approximations are based on beams on elastic foundation theory, that will be discussed in paragraph 5 2

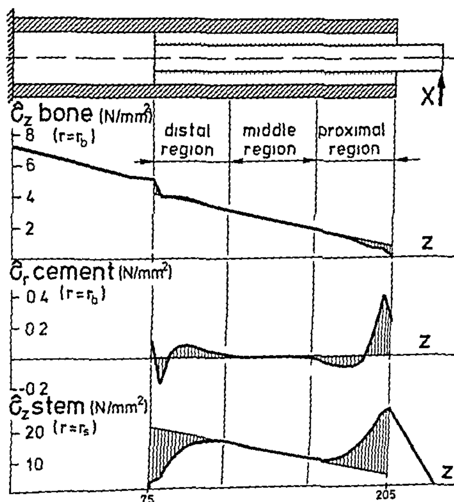


fig 5 7 With respect to its mechanical behavior, the intramedullary fixation system can be divided into three regions The middle region behaves in accordance with composite beam theory Deviations from composite beam theory in the proximal and distal regions are shown with respect to axial stresses in the bone and the stem, and to radial stresses in the cement (stem length 130 mm)

Since

$$\lambda_t = \sqrt[4]{\left\{\frac{C_t}{4F_s}\left(1+\frac{F_s}{F_b}\right)\right\}}$$

it follows that when $F_s \ll F_b$ the bone can be assumed to be rigid

If circular geometry is assumed as in the model described in chapter 3 it follows (see also appendix B) that

$$F_s = \frac{\pi}{4}E_s r_s^4 \quad F_b = \frac{\pi}{4}E_b(r_o^4 - r_b^4) \quad C_t = c_1 E_c g(\nu_c)\left(c_2 + \frac{\rho}{1-\rho}\right)$$

where c_1 c_2 constants depending on the interface conditions and
$g(\nu_c)$ expression in ν_c to be evaluated graphically
$\rho = r_s/r_b$

In this case the continuously distributed transverse load p(z) is the resultant of the stress components σ_r and τ_{rt} as shown in fig 5 9

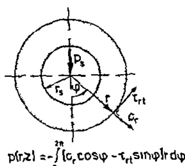


fig 5 9 Definition of the continuously distributed transverse load $p(r\ z)$ in a circular cross section $p_s(z) = p(r_s,z)$ and $p_b(z) = p(r_b\ z)$ In the beams-on-elastic foundation theory $p(r\ z) = p(z)$ hence $p_s = p_b = p$

A comparison of results (M_s M_b and p as functions of z) as calculated with the FEM model and with the method presented in this paragraph is shown in fig 5 10 The agreement in M_s and M_b is good the agreement in p is reasonable

The variables $M_s(z)$ and $M_b(z)$ can be calculated directly to axial stem and bone stresses (σ_z) the maximal values of which are denoted by $s_{zs}(z)$ and $s_{zb}(z)$ respectively as

$$s_{zs} = \frac{M_s}{W_s} \quad \text{and} \quad s_{zb} = \frac{M_b}{W_b} \tag{5 7}$$

The transverse load p(z) cannot be calculated to stresses since it depends on both σ_r and τ_{rt} (fig 5 9) Representative average stress variables $\bar{s}_{rs}(z)$ and $\bar{s}_{rb}(z)$ are introduced as

where F_s and F_b denote the flexural stiffness of the stem and the bone, respectively ($F = EI$)

Equations (5 1) and (5 2) can be solved to give

$$u_s(z) = e^{\lambda_t z} D_1(z) + e^{\lambda_t z} D_2(z) + \sum_{i=0}^{3} a_i z^i \quad (5\ 3)$$

$$u_b(z) = -\frac{F_s}{F_b} e^{\lambda_t z} D_1(z) + \frac{F_s}{F_b} e^{\lambda_t z} D_2(z) + \sum_{i=0}^{3} a_i z^i \quad (5\ 4)$$

$$p(z) = C_t\left(1 + \frac{F_s}{F_b}\right)\left(e^{\lambda_t z} D_1(z) + e^{\lambda_t z} D_2(z)\right) \quad (5\ 5)$$

where

$$D_1 = A_1 \cos\lambda_t z + A_2 \sin\lambda_t z$$

$$D_2 = A_3 \cos\lambda_t z + A_4 \sin\lambda_t z$$

$$\lambda_t = \sqrt[4]{\left\{\frac{C_t}{4}\left(\frac{1}{F_s} + \frac{1}{F_b}\right)\right\}}$$

by using the boundary conditions

$$u_b(0) = 0,\quad \frac{du_b}{dz}(0) = 0,\quad \frac{d^2u_b}{dz^2}(L) = 0,\quad \frac{d^3u_b}{dz^3}(L) = 0,\quad \frac{d^2u_s}{dz^2}(0) = 0\quad \frac{d^3u_s}{dz^3}(0) = 0,$$

$$\frac{d^2u_s}{dz^2}(L) = \frac{M_L}{F_s},\quad \frac{d^3u_s}{dz^3}(L) = -\frac{T_L}{F_s}\ ,$$

the constants A_1 through A_4 and a_0 through a_3 can be calculated which gives u_s u_b and p The bending moments in the stem and bone follow from

$$M_s(z) = F_s \frac{d^2u_s}{dz^2} \quad \text{and} \quad M_b(z) = F_b \frac{d^2u_b}{dz^2} \quad (5\ 6)$$

For these calculations a computer program was set up

The parameters that determine the mechanical behavior of the structure described by $M_s(z)$, $M_b(z)$ and $p(z)$, are C_t, F_s F_b and L The formulas presented above are valid for arbitrary (constant) cross sectional geometry of the stem and the bone, where C_t can be approximated by the formulas given in appendix B
As follows from formulas (5 3), (5 4) and (5 5) the mechanical behavior of the structure is principally characterized by the parameter λ_t

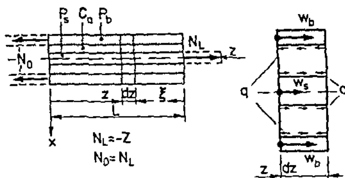


fig 5 11 Parameters and variables of the beams-on-elastic foundation model for transverse loading The axial load N_L is directed opposite to the previously defined load Z

$$P_s\frac{d^2w_s}{dz^2} + q = 0 \quad \text{and} \quad P_b\frac{d^2w_b}{dz^2} - q = 0 \tag{5 10}$$

where P_s and P_b are the compressional stiffness of stem and bone respectively ($P = EA$)

Equations (5 9) and (5 10) can be solved to give

$$w_s(z) = A_1e^{\lambda_a z} + A_2e^{\lambda_a z} + A_3 + A_4z \tag{5 11}$$

$$w_b(z) = -\frac{P_s}{P_b}A_1e^{\lambda_a z} - \frac{P_s}{P_b}A_2e^{\lambda_a z} + A_3 + A_4z \tag{5 12}$$

$$q(z) = -C_a(1 + \frac{P_s}{P_b})(A_1e^{\lambda_a z} + A_2e^{\lambda_a z}) \tag{5 13}$$

where

$$\lambda_a = \sqrt{\{C_a(\frac{1}{P_s} + \frac{1}{P_b})\}}$$

Using the boundary conditions

$$w_b(0) = 0 \quad \frac{dw_b}{dz}(L) = 0 \quad \frac{dw_s}{dz}(0) = 0 \quad \frac{dw_s}{dz}(L) = \frac{N_L}{P_s}$$

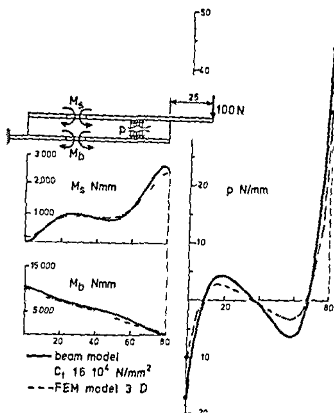


fig 5 10 Comparison of the bending moments in the stem (M_s) and the bone (M_b), and the continuously distributed transverse load (p), as calculated with the FEM model and with the beams on elastic foundation theory The curve for p(z) in the case of the FEM model is taken as $p = (p_s + p_b) / 2$, in the analytical model $p_s = p_b = p$

$$\xi_{rs} = \frac{p}{2r_s} \quad \text{and} \quad \xi_{rb} = \frac{p}{2r_b} \tag{5 8}$$

5 2 2 *Axial loading*

For axial loading the same strategy is followed as for transverse loading It is again assumed that both the stem and the bone behave in accordance with beam theory The resistance of the cement mantle to transverse loading and axial loading is neglected in this case and its axial shearing stiffness is represented by a continuous set of linear springs
The parameters of the model are shown in fig 5 11
The shearing stiffness of the cement layer C_a (N/mm²) for axial loading is defined as

$$q = C_a(w_b - w_s) \tag{5 9}$$

where $w_b(z)$ and $w_s(z)$ are the displacements in the axial direction of the bone and the stem, respectively, and q(z) (N/mm) is the continuously distributed axial shearing load that the cement exerts on the stem and the bone and vice versa

As follows directly from beam theory (or bar theory)

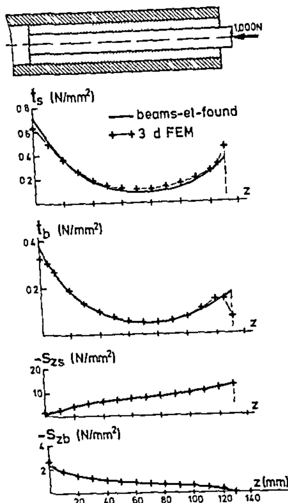


fig 5 12 Comparison of axial stem stress (s_{zs}) bone stress (s_{zb}), stem-cement interface shear stress (t_s) and bone-cement interface shear stress (t_b) upon axial loading (N_L = -1000N) as calculated with the FEM model and as calculated with the beams-on elastic foundation model

As already discussed in paragraph 5 1 the shear stress at the interfaces at both ends after the steep rise should decrease sharply to zero In this case too the model does not describe this phenomenon The calculated values for t_s and t_b at the ends should be regarded as representing maximal values that occur a little distance away from these ends in reality

5 3 Approximative formulas

As we have seen in paragraph 5 1 the fixation system can be divided into three regions where its mechanical behavior is concerned This can easily be understood if the structure is assumed to be of semi infinite length (fig 5 13)

the constants A_1 through A_4 can be calculated, which gives w_s w_b and q

The axial loads in stem and bone follow from

$$N_s(z) = P_s \frac{dw_s}{dz} \quad \text{and} \quad N_b(z) = P_b \frac{dw_b}{dz} \tag{5 14}$$

The parameters that determine the mechanical behavior of the structure described by $N_s(z)$, $N_b(z)$ and $q(z)$, are C_a P_s P_b and L, and the formulas presented are again valid for arbitrary (constant) cross sectional geometry of the stem and the bone, where C_a can be approximated by the formulas given in appendix B In the axial loading case, too it follows since

$$\lambda_a = \sqrt{\left\{\frac{C_a}{P_s}\left(1 + \frac{P_s}{P_b}\right)\right\}}$$

that if $P_s \ll P_b$ the bone can be assumed to be rigid

For circular geometry as in the model described in chapter 3 it follows (see also appendix B), that

$$P_s = \pi E_s r_s^2 \quad P_b = \pi E_b (r_o^2 - r_b^2), \quad C_a = -\frac{\pi E_c}{(1 + \nu_c)\ln\rho}$$

In this case the continuously distributed axial shearing load $q(z)$ is the resultant of the axial shear stress τ_{rz} In general

$$q(r\ z) = \int_0^{2\pi} \tau_{rz}(r\ z) r d\varphi \tag{5 15}$$

if we define $t_s(z) = \tau_{rz}(r_s\ z)$ and $t_b(z) = \tau_{rz}(r_b\ z)$ it follows that

$$q_s(z) = t_s \gamma_s \quad \text{and} \quad q_b(z) = t_b \gamma_b \tag{5 16}$$

where γ_s and γ_b (mm) are the outer stem and the inner bone circumferences respectively Due to the assumptions in the beams on elastic foundation theory $q_s = q_b = q$

The axial stress in the stem and the bone denoted by $s_{zs}(z)$ and $s_{zb}(z)$, respectively follow from

$$s_{zs} = \frac{N_s}{A_s} \quad \text{and} \quad s_{zb} = \frac{N_b}{A_b} \tag{5 17}$$

Fig 5 12 shows a comparison of bone, stem and interface shear stresses as calculated with the FEM model and as calculated using the formulas presented in this paragraph The agreement is good

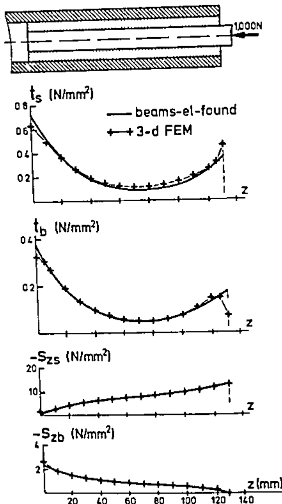


fig 5 12 Comparison of axial stem stress (s_{zs}) bone stress (s_{zb}), stem-cement interface shear stress (t_s) and bone cement interface shear stress (t_b) upon axial loading (N_L = -1000N) as calculated with the FEM model and as calculated with the beams-on-elastic foundation model

As already discussed in paragraph 5 1 the shear stress at the interfaces at both ends after the steep rise should decrease sharply to zero In this case too the model does not describe this phenomenon The calculated values for t_s and t_b at the ends should be regarded as representing maximal values that occur a little distance away from these ends in reality

5 3 Approximative formulas

As we have seen in paragraph 5 1 the fixation system can be divided into three regions where its mechanical behavior is concerned This can easily be understood if the structure is assumed to be of semi infinite length (fig 5 13)

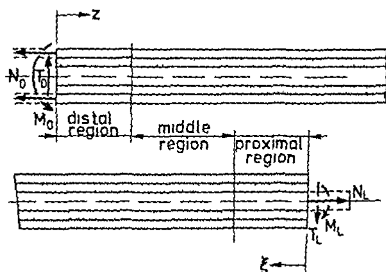


fig 5 13 On assuming the structure to be of semi infinite length, the proximal and distal regions are treated separately The loading systems for these two cases are shown

The solutions of the differential equations for axial and transverse loading (5 3) through (5 5) and (5 11) through (5 13), are again valid, also the boundary conditions for $z = 0$ remain unchanged, but the boundary conditions for $z = L$ have to be replaced by requirements of vanishing initial effects for $z \to \infty$, hence $D_1 = 0$ in formulas (5 3) through (5 5) and $A_1 = 0$ in formulas (5 11) through (5 13) After establishing the constants using the remaining boundary conditions at $z = 0$ it follows for transverse loading at the distal side that

$$M_s(z) = \frac{F_s}{F_s+F_b}\left\{M_0 - T_0 z - e^{\lambda_t z}\left(M_0 \cos\lambda_t z + \left(M_0 - \frac{T_0}{\lambda_t}\right)\sin\lambda_t z\right)\right\} \tag{5 18}$$

$$M_b(z) = \frac{F_s}{F_s+F_b}\left\{\frac{F_b}{F_s}M_0 - \frac{F_b}{F_s}T_0 z + e^{\lambda_t z}\left(M_0 \cos\lambda_t z + \left(M_0 - \frac{T_0}{\lambda_t}\right)\sin\lambda_t z\right)\right\} \tag{5 19}$$

$$p(z) = \frac{1}{2}\frac{C_t}{\lambda_t^2 F_b}\, e^{\lambda_t z}\left(M_0 \sin\lambda_t z - \left(M_0 - \frac{T_0}{\lambda_t}\right)\cos\lambda_t z\right) \tag{5 20}$$

and for axial loading that

$$N_s(z) = \frac{P_s}{P_s+P_b}N_0\left(1 - e^{\lambda_a z}\right) \quad N_b(z) = \frac{P_b}{P_s+P_b}N_0\left(1 + \frac{P_s}{P_b}e^{\lambda_a z}\right) \tag{5 21}$$

$$q(z) = -\frac{\lambda_a P_s}{P_s+P_b} N_0 e^{\lambda_a z} \qquad (5\ 22)$$

The same kind of formulas can be established for the other (proximal) side replacing z by ξ F_s by F_b P_s by P_b M_0 by M_L T_0 by T_L and N_0 by N_L
On both sides separately the system has a force introduction region the length of which is determined by $e^{\lambda_t z}$ and $e^{\lambda_a z}$ hence by λ_t and λ_a For higher z the expressions for the loading variables reduce to

$$M_s(z) = \frac{F_s}{F_s+F_b}(M_0 - T_0 z) \quad M_b(z) = \frac{F_b}{F_s+F_b}(M_0 - T_0 z) \quad p(z) = 0 \qquad (5\ 23)$$

$$N_s(z) = \frac{P_s}{P_s+P_b} N_0 \quad N_b(z) = \frac{P_b}{P_s+P_b} N_0 \quad q(z) = 0 \qquad (5\ 24)$$

the well known formulas for composite beam theory applying to an infinitely long composite structure (e g. Muskhelshvili 1963 Bartel and Desormeaux 1976a) In this case the flexural and compressional stiffness of the cement layer is neglected allowed since $F_c \ll F_s+F_b$ and $P_c \ll P_s+P_b$
Whether or not these formulas apply to the middle region or in other words whether or not there is a middle region depends on the stem length and the values of λ_a and λ_t For transverse loading the traditional criterion for beams-on elastic foundation theory can be used (Hetenyi 1946)

$\lambda_t L \leq \frac{\pi}{4}$	short beam both the stem and the bone can be assumed as rigid to find a good approximation of p(z)
$\frac{\pi}{4} < \lambda_t L < \pi$	intermediate beam length both sides of the system influence each other the full theory has to be used composite beam theory is not appropriate for any section
$\lambda_t L \geq \pi$	long beam the behavior of the proximal and distal ends are independent by approximation and the structure can be analyzed by analyzing the proximal region the middle region and the distal region separately

This is illustrated in fig 5 14 where the expression $e^{\lambda_t z}\cos\lambda_t z$ that principally determines the behavior of p(z) is shown graphically for a stem length of 80 mm and different values of λ_t
When the same criterion is used for axial loading for λ_a it follows for $\lambda_a L = \pi$ $e^{\lambda_a L/2} \approx 0\ 2$ hence 80% of the *initial effect would have vanished* at half the stem length so there would still be a *significant* interaction between both sides For $\lambda_a L \approx 4\ 6$ 90% of the effect would have vanished and 95% for $\lambda_a L \approx 6\ 0$

Fig 5 15 shows a comparison of results *for* p(z) and q(z) as calculated using the beams on elastic foundation theory presented in *paragraph* 5 2 and using the semi infinite approximation for both sides (formulas (5 20) (5 22) and their *equivalents* for the proximal side) The semi infinite approximation is quite good *where* p(z) is concerned In the case of axial loading both ends apparently still *influence each other* which was to be expected since $\lambda_a L \approx 2\ 9$ in this case *However even for this low value* the approximation of q(z) is not bad

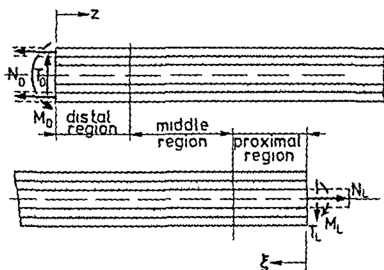


fig 5 13 On assuming the structure to be of semi infinite length, the proximal and distal regions are treated separately The loading systems for these two cases are shown

The solutions of the differential equations for axial and transverse loading (5 3) through (5 5) and (5 11) through (5 13) are again valid also the boundary conditions for $z = 0$ remain unchanged, but the boundary conditions for $z = L$ have to be replaced by requirements of vanishing initial effects for $z \to \infty$, hence $D_1 = 0$ in formulas (5 3) through (5 5) and $A_1 = 0$ in formulas (5 11) through (5 13) After establishing the constants, using the remaining boundary conditions at $z = 0$ it follows for transverse loading at the distal side that

$$M_s(z) = \frac{F_s}{F_s+F_b}\left\{M_0 - T_0 z - e^{\lambda_t z}\left(M_0\cos\lambda_t z + \left(M_0 - \frac{T_0}{\lambda_t}\right)\sin\lambda_t z\right)\right\} \quad (5\ 18)$$

$$M_b(z) = \frac{F_s}{F_s+F_b}\left\{\frac{F_b}{F_s}M_0 - \frac{F_b}{F_s}T_0 z + e^{\lambda_t z}\left(M_0\cos\lambda_t z + \left(M_0 - \frac{T_0}{\lambda_t}\right)\sin\lambda_t z\right)\right\} \quad (5\ 19)$$

$$p(z) = \frac{1}{2}\frac{C_t}{\lambda_t^2 F_b}\, e^{\lambda_t z}\left(M_0\sin\lambda_t z - \left(M_0 - \frac{T_0}{\lambda_t}\right)\cos\lambda_t z\right) \quad (5\ 20)$$

and for axial loading that

$$N_s(z) = \frac{P_s}{P_s+P_b}N_0\left(1 - e^{\lambda_a z}\right) \qquad N_b(z) = \frac{P_b}{P_s+P_b}N_0\left(1 + \frac{P_s}{P_b}e^{\lambda_a z}\right) \quad (5\ 21)$$

When $\lambda_t L \geq \pi$ and $\lambda_a L \geq \pi$ the structure can be divided into a proximal a middle and a distal region in which the most important stress components can be calculated using simple formulas as summarized in table 5 11 From these formulas the stresses in the stem and the bone (s_{zs} and s_{zb}) and the normal and shear stresses at the interfaces (ς_{rs} ς_{rb} t_s and t_b) can be calculated for given geometry

		Transverse loading (M_L and T_L)	Axial loading (N_L)
proximal region			
	stem	$M_s(L) = M_L$	
cemen /interfaces		$p(L) = \frac{1}{2}\frac{C_t}{\lambda_t^2 F_s}(M_L + \frac{T_L}{\lambda_t})$	$q(L) = -\frac{\lambda_a P_b}{P_s + P_b} N_L$
middle region			
	stem	$M_s(\xi) = \frac{F_s}{F_s + F_b}(M_L + T_L \xi)$	$N_s(\xi) = \frac{P_s}{P_s + P_b} N_L$
	bone	$M_b(\xi) = \frac{F_b}{F_s + F_b}(M_L + T_L \xi)$	$N_b(\xi) = \frac{P_b}{P_s + P_b} N_L$
distal region			
	bone	$M_b(0) = M_L + T_L$	$N_b(0) = N_L$
cement/interfaces		$p(0) = -\frac{1}{2}\frac{C_t}{\lambda_t^2 F_b}(M_L + T_L L - \frac{T_L}{\lambda_t})$	$q(0) = -\frac{\lambda_a P_s}{P_s + P_b} N_L$

table 5 11 Approximative formulas describing the most important loading variables in the stem (M_s and N_s) the bone (M_b and N_b) in the cement layer and at the interfaces (p and q) in the proximal, middle and distal regions respectively (see also fig 5 13)

It should be remarked here that the axial stress in the cement layer can also be approximated in the middle region using composite beam theory However as was found in paragraph 5 1 (fig 5 6) the value of this stress component in the cement in the middle region is quite low in comparison to stresses in the proximal and the distal regions

5 4 FEM beam analysis

The model described in paragraph 5 2 where stem and bone separately are assumed to behave in accordance with beam theory and where the intermediate layer is assumed to react as a continuous set of linear springs can also be simulated using simple FEM beam analysis The reason for developing su h a model is the possibility of taking nonconstant cross-sectional geometries of the stem and the bone into account and likewise of modeling

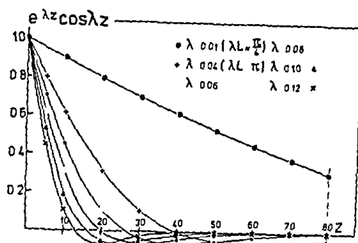


fig 5 14 The function $e^{\lambda z}\cos\lambda z$ for different (realistic) values of λ. When $\lambda L \lessapprox \frac{\pi}{4}$ the function is practically linear

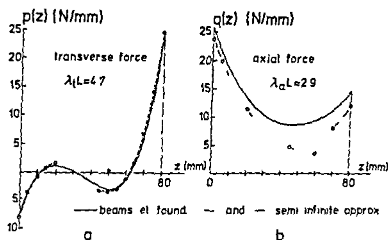


fig 5 15 A comparison of results for p(z) (a) and q(z) (b) as calculated for a structure of finite length and as calculated assuming semi infinite length on both sides, respectively

Summarizing, it can be said that the application of the approximative semi infinite beams on elastic foundation theory gives excellent opportunities to characterize the mechanical behavior of the intramedullary bone prosthesis structure and to develop a fundamental, general concept on the relations between stresses and the most important structural para meters

A first characterization follows from the quantities $\lambda_t L$ and $\lambda_a L$, where

$$\lambda_t = \sqrt[4]{\left\{\frac{C_t}{4}\left(\frac{1}{F_s} + \frac{1}{F_b}\right)\right\}} \quad \text{and} \quad \lambda_a = \sqrt{\left\{C_a\left(\frac{1}{P_s} + \frac{1}{P_b}\right)\right\}}$$

and C_t and C_a can be evaluated using the formulas presented in appendix B

C_3 C_1 and L Apart from these there are other important parameters for example the flexural and compressional stiffness of the cement mantle (F_c and P_c) and the outer stem and the inner bone circumferences (γ_s and γ_b) which do not influence the mechanical behavior so much in general but do influence the local stress values These parameters too should be represented adequately in the model

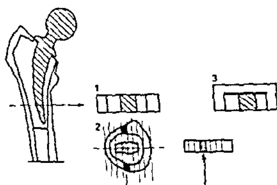


fig 5 17 Three different methods of representing the hip endoprosthesis fixation system in a plane model 1 as it appears in a longitudinal section 2 using composite materials theory to take the out-of plane material stiffness into account (see also fig 5 18) 3 using side plates (a spanning element layer) to take the medial lateral cortex connection into account

Three different methods of modeling in two dimensions have been reported in the literature (fig 5 17) The simplest method is the one in which a longitudinal plane mid section of the structure is modeled as it appears for instance on an X ray (fig 5 17 1 e g Andriacchi *et al* 1975 Kwak *et al* 1979) In this case no connection exists in the model between the lateral and the medial cortex Hence apart from the question whether this model can take the correct parameter values of the system into account the model in essence consists of three beams connected by two elastic layers Since the elastic lines (or neutral axes) of these beams do not coincide a sandwich construction results in which the stiffness is to a great extent determined by shear at the cement bone interfaces (e g Girkman 1963) which is a quite unrealistic representation of the structure

A second method is the one in which the theory of composite materials is used (fig 5 17 2 McNeice *et al* 1975 1976) In this case the system is modeled as in the previous case but the stiffness of the out-of plane material is taken into account by calculating a combination of an effective thickness (t_e) and Young s modulus (E_e) for every plane element as shown in fig 5 18

E_1 E_2 E_3 E_4 E_5 → E_e $t_eE_e = \Sigma tE$

fig 5 18 In using the composite materials theory the out-of-plane stiffness of the structure consisting in this case of three materials is represented by a plane element whose stiffness characteristics are calculated from the three original materials taking into account their thickness and Young s moduli

variations in the elastic moduli of the three materials in order to investigate influences of incomplete cement mantles and bone resorption Spongeous bone layers of varying thickness too, can be taken into account in such a model
In this model the stem and the bone are represented by a number of beam elements and the cement mantle by special spring elements that simulate the stiffness of the layer in the axial and transverse directions (C_a and C_t), as shown in fig 5 16 In the model, the quantities $M_s(z)$, $M_b(z)$, $N_s(z)$, $N_b(z)$ $q(z)$, $p(z)$, $s_{zs}(z)$, $s_{zb}(z)$, $\bar{s}_{rs}(z)$, $\bar{s}_{rb}(z)$, $t_s(z)$ and $t_b(z)$ are calculated just as with the model described in paragraph 5 2 On comparison of results from both models the agreement was found to be excellent

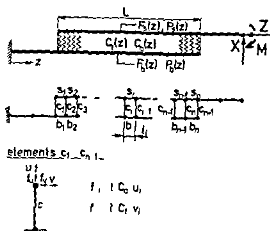


fig 5 16 Characterization of the FEM beam model, the elements s_i and b_i are beam elements representing the stem and the bone, respectively The cement mantle is represented by spring elements (c_i), with certain stiffness characteristics in axial and transverse directions

This model can easily be extended to three dimensional geometry and a more sophisticated (three dimensional) representation of the cement mantle The restriction of this model is the requirement that the bone and the stem separately should behave in accordance with beam theory

5 5 Two dimensional (plane) FEM analysis

It is the object of this paragraph to discuss the possibilities and limitations of two dimensional FEM analyses rather than present results of such a model Although a two-dimensional FEM analysis of the simplified model presented in chapter 3 was carried out and will be used in chapter 6 it was apparent that the relation between the results of the three dimensional model and those of the two dimensional model was rather confusing Many two dimensional models have been presented in the literature as discussed in chapter 2, and it appears to be worth while to evaluate these models which can be done by using the previously developed concepts

Obviously the modeling has to be carried out in such a way that the essential characteristics of the structure are represented in the model As was shown in the previous paragraphs the essential parameters of the intramedullary bone prosthesis structure are λ_t λ_a F_s F_b P_b, P_s

parameter		circular geometry	rectangular geometry
P_b		$\pi E_b(r_o^2 - r_b^2)$	depending on side plate dimensions
F_b		$\frac{\pi}{4} E_b(r_o^4 - r_b^4)$	
γ_b		$2\pi r_b$	$2d$
P_s		$\pi E_s r_s^2$	$2E_s d r_s$
F_s		$\frac{\pi}{4} E_s r_s^4$	$\frac{2}{3} E_s d r_s^3$
γ_s		$2\pi r_s$	$2d$
P_c		$\pi E_c(r_b^2 - r_s^2)$	$2d(r_b - r_s)$
F_c		$\frac{\pi}{4} E_c(r_b^4 - r_s^4)$	$\frac{1}{6} d(r_b - r_s)^3$
C_a	(1)	$-\frac{\pi E_c}{(1+\nu_c)\ln\rho}$	$\frac{dE_c}{(1+\nu_c)(r_b-r_s)}$
C_t	(1)	$\frac{4\rho E_c(1\ \nu_c)}{(1-\rho)(1+\nu_c)(1-2\nu_c)}$	$\frac{2dE_c(1-\nu_c)}{(r_b-r_s)(1+\nu_c)(1-2\nu_c)}$
λ_a^2	(2)	$-\frac{E_c}{E_s}\frac{1}{(1+\nu_c)\ln\rho}\frac{1}{r_s^2}$	$\frac{E_c}{E_s}\frac{1}{2r_s(r_b-r_s)(1+\nu_c)}$
λ_t^4	(2)	$\frac{E_c}{E_s}\frac{4\rho(1\ \nu_c)}{(1-\rho)(1+\nu_c)(1-2\nu_c)}\frac{1}{\pi r_s^4}$	$\frac{3}{4}\frac{E_c}{E_s}\frac{1-\nu_c}{(r_b-r_s)(1+\nu_c)(1-2\nu_c)}\frac{1}{r_s^3}$

table 5 III Formulas describing the characteristic parameters in an axisymmetric structure and in a two-dimensional (plane) model (see fig 5 19) (1) rough approximation see appendix B (2) to make a first-order general comparison possible $\lambda_a^2 \approx C_a/P_s$ and $\lambda_t^4 \approx C_t/4F_s$ are taken

In conclusion it is evident that unless axial and transverse loading are investigated with two different models and a method of scaling is introduced the relation between the mechanical behavior of an intramedullary bone prosthesis structure and that of a two dimensional model is not very well defined This does not imply that two-dimensional FEM models are worthless in this case when side plates are applied and care is taken to choose the dimensions in such a way as to meet the above mentioned requirements as fully as possible tendencies could certainly be investigated in a relative sense But these two-dimensional models certainly do not have the accuracy that the visual apparent agreements between the models and the real structure suggest. Furthermore a comparison of results of different two dimensional models is difficult

Apart from the fact that in this case, too a sandwich construction results the essential characteristics of the structure are not modeled correctly, because those elements that represent the stem also incorporate the stiffness of a piece of cement and a piece of bone and those elements that represent the cement *incorporate part of the bone What is modeled* correctly in using this method is the overall stiffness of the full cross section McNeice *et al* (1975) show in their results that the stresses in the stem increase by a factor of three if loosening occurs at the stem cement interface This is exactly what would happen in a sandwich construction, as they in fact analyzed, but not in the real structure, where the *lateral and medial cortex are connected, as will be shown in the next chapter*

A third method of modeling is the one in which the connection between the lateral and medial cortex of the bone is taken into account by applying a side plate or a 'spanning element' layer in the model (fig 5 17 3, e g Hampton *et al*, 1976, Svensson *et al*, 1977) This method is the only one that gives the option of modeling the system as a two beam structure in a plane and hence the only one that is suitable However, it is questionable whether even in using this method the essential parameters mentioned previously can be *adequately represented*

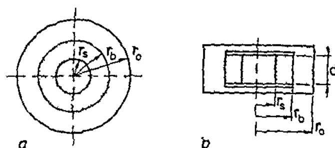


fig 5 19 A plane representation (b) of a structure with axisymmetric cross section (a), applying side plates

As an example a system with circular cross section is assumed (fig 5 19 a) This structure has to be represented in a plane model, taking a 'spanning-element layer into account (fig 5 19 b) The real values of the essential parameters and those in the two dimensional representation can then be compared as shown in table 5 III

On comparing these quantities it follows (when E_c, E_s, r_s and r_b are equal in both models), that

$$\frac{\lambda_a \text{ (circ. geom)}}{\lambda_a \text{ (plane geom)}} \approx \sqrt{-\frac{2(1-\rho)}{\rho \ln \rho}} \quad \text{and} \quad \frac{\lambda_t \text{ (circ geom)}}{\lambda_t \text{ (plane geom)}} \approx \sqrt[4]{\frac{16}{3\pi}} \approx 1\ 15$$

For $\rho = 0\ 5$ $\lambda_a(\text{circ})/\lambda_a(\text{plane}) \approx 1\ 7$ and for $\rho = 0\ 8$ $\lambda_a(\text{circ})/\lambda_a(\text{plane}) \approx 1\ 5$

Apparently the ratios of λ_a and λ_t are independent of d and hence since only d can be freely adjusted in the model, the ratios are more or less fixed

Hence for axial loading especially the most crucial parameter of the circular structure is badly modeled in the plane representation As follows from table 5 III also d can never be chosen in such a way that all other requirements are fulfilled If $r_s = 5$ mm and $r_b = 10$ mm then $-\pi/\ln\rho \approx 4\ 5$ and $4\rho/(1-\rho) = 4$, hence in order to satisfy requirements for equal C_a d should be equal to 22 65 and to satisfy requirements for C_t d should be equal to 10

The requirements for P_s and F_s could be satisfied by assuming non uniform thickness of the stem in the plane model If d has been chosen to satisfy requirements for C_a or C_t nothing more can be done to satisfy requirements for F_c, P_c γ_s and γ_b

parameter		circular geometry	rectangular geometry
P_b		$\pi E_b(r_o^2 - r_b^2)$	depending on side plate dimensions
F_b		$\frac{\pi}{4} E_b(r_o^4 - r_b^4)$	
γ_b		$2\pi r_b$	2d
P_s		$\pi E_s r_s^2$	$2E_s d r_s$
F_s		$\frac{\pi}{4} E_s r_s^4$	$\frac{2}{3} E_s d r_s^3$
γ_s		$2\pi r_s$	2d
P_c		$\pi E_c(r_b^2 - r_s^2)$	$2d(r_b - r_s)$
F_c		$\frac{\pi}{4} E_c(r_b^4 - r_s^4)$	$\frac{1}{6} d(r_b - r_s)^3$
C_a	(1)	$-\frac{\pi E_c}{(1+\nu_c)\ln\rho}$	$\frac{dE_c}{(1+\nu_c)(r_b-r_s)}$
C_t	(1)	$\frac{4\rho E_c(1-\nu_c)}{(1-\rho)(1+\nu_c)(1-2\nu_c)}$	$\frac{2dE_c(1-\nu_c)}{(r_b-r_s)(1+\nu_c)(1-2\nu_c)}$
λ_a^2	(2)	$-\frac{E_c}{E_s}\frac{1}{(1+\nu_c)\ln\rho}\frac{1}{r_s^2}$	$\frac{E_c}{E_s}\frac{1}{2r_s(r_b-r_s)(1+\nu_c)}$
λ_t^4	(2)	$\frac{E_c}{E_s}\frac{4\rho(1-\nu_c)}{(1-\rho)(1+\nu_c)(1-2\nu_c)}\frac{1}{\pi r_s^4}$	$\frac{3}{4}\frac{E_c}{E_s}\frac{1-\nu_c}{(r_b-r_s)(1+\nu_c)(1-2\nu_c)}\frac{1}{r_s^3}$

table 5 III Formulas describing the characteristic parameters in an axisymmetric structure and in a two-dimensional (plane) model (see fig 5 19) (1) rough approximation see appendix B (2) to make a first-order general comparison possible $\lambda_a^2 \approx C_a/P_s$ and $\lambda_t^4 \approx C_t/4F_s$ are taken

In conclusion it is evident that unless axial and transverse loading are investigated with two different models and a method of scaling is introduced the relation between the mechanical behavior of an intramedullary bone prosthesis structure and that of a two-dimensional model is not very well defined This does not imply that two-dimensional FEM models are worthless in this case when side plates are applied and care is taken to choose the dimen sions in such a way as to meet the above mentioned requirements as fully as possible ten dencies could certainly be investigated in a relative sense But these two dimensional models certainly do not have the accuracy that the visual apparent agreements between the models and the real structure suggest Furthermore a comparison of results of different two dimensional models is difficult

Apart from the fact that in this case, too, a sandwich construction results, the essential characteristics of the structure are not modeled correctly, because those elements that represent the stem also incorporate the stiffness of a piece of cement and a piece of bone and those elements that represent the cement incorporate part of the bone What is modeled correctly in using this method is the overall stiffness of the full cross section McNeice *et al* (1975) show in their results that the stresses in the stem increase by a factor of three if loosening occurs at the stem cement interface This is exactly what would happen in a sandwich construction, as they in fact analyzed, but not in the real structure, where the lateral and medial cortex are connected, as will be shown in the next chapter

A third method of modeling is the one in which the connection between the lateral and medial cortex of the bone is taken into account by applying a side plate or a 'spanning element' layer in the model (fig 5 17 3, e g Hampton *et al*, 1976, Svensson *et al*, 1977) This method is the only one that gives the option of modeling the system as a two beam structure in a plane and hence the only one that is suitable However, it is questionable whether even in using this method the essential parameters mentioned previously can be adequately represented

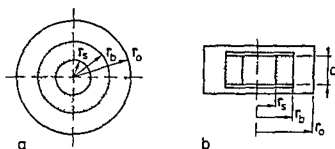


fig 5 19 A plane representation (b) of a structure with axisymmetric cross section (a), applying side plates

As an example, a system with circular cross section is assumed (fig 5 19 a) This structure has to be represented in a plane model, taking a 'spanning element layer into account (fig 5 19 b) The 'real values of the essential parameters and those in the two dimensional representation can then be compared as shown in table 5 III

On comparing these quantities it follows (when E_c, E_s r_s and r_b are equal in both models), that

$$\frac{\lambda_a \text{ (circ geom)}}{\lambda_a \text{ (plane geom)}} \approx \sqrt{-\frac{2(1-\rho)}{\rho\ln\rho}} \quad \text{and} \quad \frac{\lambda_t \text{ (circ geom)}}{\lambda_t \text{ (plane geom)}} \approx \sqrt[4]{\frac{16}{3\pi}} \approx 1\ 15$$

For $\rho = 0\ 5$, $\lambda_a(\text{circ})/\lambda_a(\text{plane}) \approx 1\ 7$ and for $\rho = 0\ 8$, $\lambda_a(\text{circ})/\lambda_a(\text{plane}) \approx 1\ 5$

Apparently the ratios of λ_a and λ_t are independent of d and hence since only d can be freely adjusted in the model the ratios are more or less fixed

Hence for axial loading especially the most crucial parameter of the circular structure is badly modeled in the plane representation As follows from table 5 III also, d can never be chosen in such a way that all other requirements are fulfilled If $r_s = 5$ mm and $r_b = 10$ mm, then $-\pi/\ln\rho \approx 4\ 5$ and $4\rho/(1-\rho) = 4$, hence in order to satisfy requirements for equal C_a d should be equal to 22 65 and to satisfy requirements for C_t, d should be equal to 10

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CHAPTER SIX

INFLUENCES OF NEGLECTED ASPECTS OF THE STRUCTURE

In this chapter some properties of the intramedullary bone prosthesis structure that have been neglected in the previously discussed models and that may influence the mechanical behavior of the system will be discussed These properties are the possible presence of locked in cement stresses more complicated mechanical conditions at the interfaces a non-constant cross-sectional geometry of the stem and a few others

6 1 Locked in thermal stresses

Due to the cooling of the acrylic cement immediately after the polymerization process the cement layer will shrink around the stem (see also section I)
This will result in locked in stresses that may influence the mechanical behavior of the structure On these (initial) stresses the stresses resulting from the joint loading will have to be superimposed and moreover they may influence the mechanical condition of the stem cement interface that will behave as rigidly connected so long as compression is present
When the temperature distribution in the cement right after the polymerization process is known the shrinkage stresses in an axisymmetric model consisting of bone cement around a (rigid) stem can be calculated (Timoshenko and Goodier 1970) Using data on tempera ture distributions as discussed in section II these calculations were carried out for different stem dimensions and cement properties (Huiskes and de Wijn 1979) Fig 6 1 shows an example of results

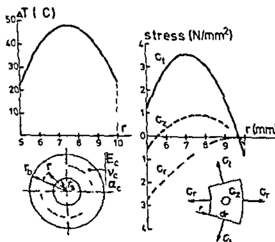


fig 6 1 Locked in thermal stresses in a model of a slice of bone cement The initial tempe rature distribution ΔT (according to fig 7 7 section II) and the radial (σ_r) axial (σ_z) and circumferential (σ_t) stress components are shown Parameter values E_c = 2 000 N/mm² ν_c = 0 33 coefficient of linear expansion α_c = 5x10⁻⁵ C⁻¹ (according to Ahmed et al 1977) In the model the properties are taken as inde pendent of the temperature plane strain state is assumed

It is evident, looking at these results, that for detailed investigations truly three dimensional models should be used FEM beam models as presented in paragraph 5 4 are more dependable, though less refined than two dimensional models

5 6 Conclusions

A simplified axisymmetric model of intrameduallary bone prosthesis structures was analy using various methods A three dimensional FEM model was developed which gives detailed information on the stress distribution in the structure

By comparison of some results with those of strain-gauge experiments on a cadaveric femur with hip endoprostheses, a qualitative agreement was apparent

By making some additional simplifying assumptions, an analytical solution for the most important stress components in the structure could be found by applying beams on elastic foundation theory The most important parameters that characterize the mechanical performance of the structure were thus established

It was found that the structure can be divided into three regions that can be analyzed separately, using quite simple formulas to calculate the most important stress components

The theory, applied here for the analytical solutions, can be extended towards non constant cross-sectional geometry, for example using minimal potential energy principles (Raleigh Ritz) to find a solution Such a solution, however, would not be in closed form, so that numerical methods would have to be applied

A method of this kind was used by Calderale *et al* (1977), for transverse loading

In the present study a FEM beam model was chosen for an extension towards a more rea geometrical description because this method offers excellent options for model refinement and is quite cheap and practical in use

By applying the concepts developed in this chapter, two dimensional FEM models could be evaluated and it was found that an intramedullary bone prosthesis structure is not very well suited for such representation and that, moreover, many pitfalls are evident in the modeling process

It is felt that the models presented here will give reasonable first order approximations of the intramedullary fixation system mechanical behavior, which implies that the most important parameters of the structure are adequately represented in the models It will be shown in chapters 7 and 8 that the models can conveniently be used to develop quantitative guidelines for implant design and implantation procedures

In the following chapter the influences of properties of the structure that were neglected in the models will be discussed

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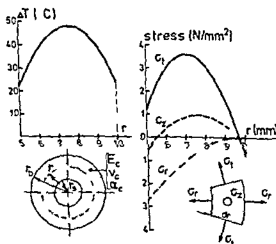


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The radial (compressional) stress at the stem cement interface reaches a value of approximately 2 5 N/mm² and the hoop stress in the middle of the cement mass 3 5 N/mm²
Comparable results were reported by Ahmed *et al* (1977), who have studied the same kind of model These values are quite sensitive to the thickness of the stem For a stem 15 mm in diameter the stress values approximately double if the same initial temperature is assumed However, as was shown in section II, in a thin cement layer the temperature will be much less The hoop stress and the axial stress are also quite sensitive to Poisson's ratio of the cement, while all three stress components are proportional to Young's modulus
The calculated stress values are of the same order of magnitude as the values that have been found to result from the joint loading (appendix A) and thus would certainly interfere with the mechanical behavior of the structure
However, acrylic cement is known to creep, especially under conditions as in the body (see also section I) In a relaxation test of a rod of acrylic cement in water at 37°C initially under a tensile stress of 4 N/mm², it was found that the stress decreased by 75% in approximately 170 hrs (7 days), as is shown in fig 6 2 (Huiskes and de Wijn, 1979) Extrapolating this data, it can be assumed that after approximately 70 days the stress would have decreased by 90% and after a year would have practically vanished

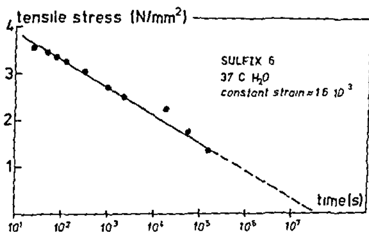


fig 6 2 Stress relaxation in a test bar of acrylic cement in tension

6 2. Mechanical conditions at the interfaces

As mentioned in section I there is no chemical bond between the stem and the cement nor between the bone and the cement Due to mechanical interlocking of cement and (spongeous) bone the cement bone interface may be able to transfer tensile stresses to some extent, although even this is doubtful when a soft fibrous tissue layer is present The stem cement interface will certainly disconnect on tension, while the shear resistance depends solely on friction Friction, at the stem cement interface as well as at the cement bone interface depends on the roughness of the contact surfaces and on the compressional stress, hence also on initial locked in stresses
It is rather difficult to take the interface conditions into account in a stress analysis since not enough accurate data is available for an adequate description Moreover the conditions will vary considerably and change in the course of time The object of this paragraph is to roughly evaluate how the interface conditions affect the stress distribution in the intra medullary fixation system In the first part it will be shown that loosening upon tension and

slip at the stem cement interface significantly affect the stress distribution in the cement using a two dimensional FEM model that can take these phenomena into account In the second and third parts the problem will be approached in a more fundamental fashion using the concepts developed in paragraph 5 2
The influence of a loose stem will only be evaluated for transverse loading For axial loading the interface conditions would very much depend on friction and on the tapering of the stem When the stem is not held by the friction forces it will simply subside until it again finds support If the stem is held by the friction forces the interfaces can be assumed to be rigidly connected From a mechanical point of view this problem is further complicated because the friction forces might be exceeded locally

6 2 1 *Numerical evaluation*

The FEM programs as used here offer options to define conditions at contact regions The condition that no tensile stress occurs between two materials can also be taken into account by applying an iterative procedure (Banens 1977) This method was used for the stem cement interface in a two dimensional model The model and its parameters are described in fig 6 3 A spanning-element layer was used to model the medial lateral cortex connection as discussed in paragraph 5 5 Material properties loading and dimensions in the x z plane were chosen in accordance with the axisymmetric model described in chapter 3

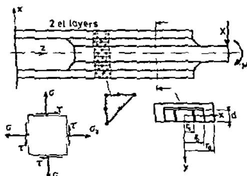


fig 6 3 A two-dimensional FEM model of the simplified intramedullary fixation structure A spanning-element layer (or side plate) is applied dimensions and stress components are given An element with triangular geometry and 6 nodal points was used the displacement field in the element is quadratic Note that the x-coordinate is defined as positive opposite to the three-dimensional FEM model (chapter 3)

Dimensions in the x y plane were chosen in such a way that the flexural and compressional stiffness of stem and bone (F_s F_b P_s and P_b) were equal to those in the axisymmetric model As discussed in paragraph 5 5 these measures are not sufficient to obtain equivalent results
Calculations were carried out for two cases A rigidly connected stem cement interface and slip and no tension at the interface Fig 6 4 shows a comparison of stresses at the stem cement interfaces as calculated for the two cases apparently the stress distribution in the cement is greatly influenced when a loose stem is assumed
The stresses in the cement at the cement bone interface also differ, as is shown for σ_x in

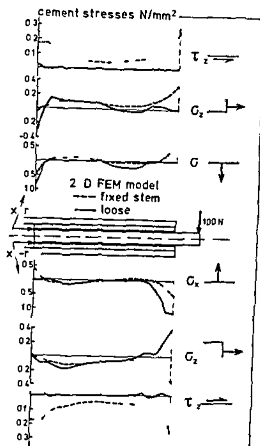


fig 6 4 Stress components in the cement at the stem cement interface on both sides of the stem, calculated for a rigidly fixed interface and as calculated simulating slip and loosening upon tension The noise in the courses of τ_{xy} for the latter case is due to inaccuracies in the solution procedure

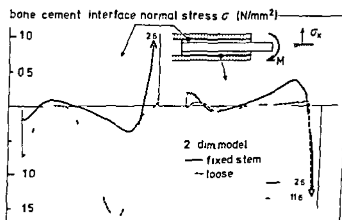


fig 6 5 Transverse stresses at the cement bone interface as calculated for a rigidly connected stem cement interface and as calculated simulating slip and loosening upon tension at this interface Apparently the latter phenomenon results in the effect that at the cement bone interface also, hardly any tensile stress is present The same effect was found for the shear stresses

fig 6 5 Apparently only very slight tensile stresses occur at this interface in the loose stem case Shear stresses too were found to be very low at this interface Hence little difference would be found for the stress distribution in the cement if the cement bone interface were also assumed as loose in addition to the stem cement interface The stem stresses were found to be slightly different as shown in fig 6 6 It should be noted that the stem stresses do not increase very much in the loose stem case as would be found for a sandwich construction as discussed in paragraph 5 5 where no side plates are applied in the model The (axial) stresses in the bone do not change significantly for a loose stem

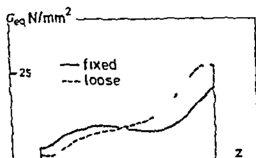


fig 6 6 A comparison of stem (equivalent) stresses as calculated simulating a rigidly connected stem-cement interface and simulating slip and loosening-upon tension at this interface

From the stresses normal to the interface (σ_x) as calculated in the model the continuously distributed transverse load p(z) as defined in paragraph 5 2 can be derived simply by superposition of the stresses on either side of the stem multiplied by the stem thickness in y direction (d) It then follows (fig 6 7) that the difference between the results for the two cases is not very outspoken It thus appears that the interface condition has a general effect by which for instance p(z) is affected and $M_s(z)$ and $M_b(z)$ will also be affected and a local effect by which the local stress values as for instance is apparent in fig 6 4 are affected Both effects will be evaluated separately in the remainder of this paragraph

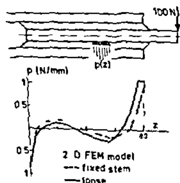


fig 6 7 A compari on of the continuously distributed transverse loads p(z) on the stem as calculated from the FEM results concerning a fixed and a loose stem-cement inter face

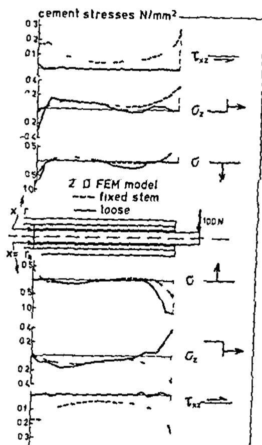


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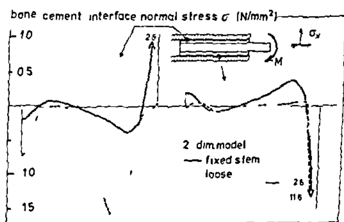


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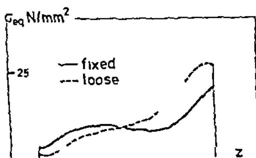


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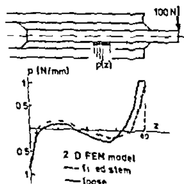


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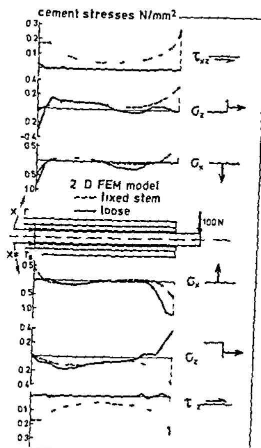


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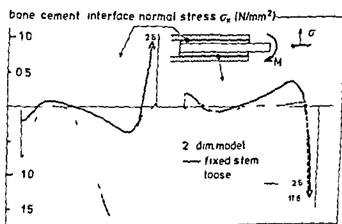


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6 2 3 *The local effect*

The local effect is caused by the circumstance that in the loose case only approximately half of the stem circumference is available to transfer loading As was shown in paragraph 5 2 (fig 5 9) for a fixed stem $p_s(z)$ is found from

$$p_s(z) = -\int_0^{2\pi} (\sigma_r \cos\varphi - \tau_{rt} \sin\varphi) r_s d\varphi$$

Because $\sigma_r = \hat{\sigma}_r \cos\varphi$ $\tau_{rt} = \hat{\tau}_{rt} \sin\varphi$ and $\hat{\tau}_{rt}$ is always opposite in sign as compared to $\hat{\sigma}_r$, it follows that

$$|p_s(z)| = \pi r_s (|\hat{\sigma}_r| + |\hat{\tau}_{rt}|) \text{ for a fixed stem} \tag{6 1}$$

For the case of the loose stem (assuming $\tau_{rt} = 0$) σ_r can be approximated by assuming it to be distributed along half of the stem circumference (fig. 6 9) as a cosine function in φ $\sigma_r = \hat{\sigma}_r \cos\varphi$ $-\frac{\pi}{2} \leq \varphi \leq \frac{\pi}{2}$ so that

$$|p_s(z)| = \frac{\pi}{2} r_s |\hat{\sigma}_r| \text{ for a loose stem} \tag{6 2}$$

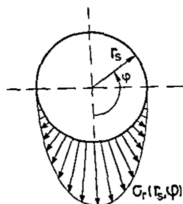


fig 6 9 Radial stress distribution at the stem cement interface In the case of a loose stem, assumed as a cosine function along half the circumference

It thus follows for $p_s(z)$ with the same local value that $\hat{\sigma}_r$ is at least twice as high in the loose case compared to the fixed case

The local influence of a loose stem for a given local value of $p(z)$ was evaluated using a FEM model of a slice of the (axisymmetric) intramedullary fixation system assuming the previously mentioned expression for σ_r (Huiskes and Schouten 1979) an example of which calculations is given in fig 6 10 It is evident that for given $p(z)$ the radial stress as well as the hoop stress will be much higher in the loose case In these calculations it was again found that at the cement bone interface the radial stress was distributed only along half the circumference hence it would make very little difference if this interface were

6 2 2 *The general effect*

It was shown in paragraph 5 2 that, upon transverse loading, the mechanical behavior of the structure is principally determined by the parameters λ_t, F_s, F_b, C_t and L For a loose stem only C_t is affected and, through C_t also λ_t If we assume circular geometry (axisymmetric model) the value of C_t can be approximated by (appendix B)

$C_t \approx 6\ 2E_c(0\ 24 + \frac{\rho}{1-\rho})$ for a rigidly connected interface and

$C_t \approx 2\ 1E_c(0\ 24 + \frac{\rho}{1-\rho})$ for a loose interface

It then follows that

C_t(loose stem)/C_t(fixed stem) $\approx$ 0 34
λ_t(loose stem)/λ_t(fixed stem) $\approx$ 0 76

The stem will thus feel a more flexible layer in the loose case and the force introduction regions at the proximal and the distal sides will be more extended
Also the maximal values of p(z) at the proximal and distal sides will be lower in the loose case, since both depend on C_t/λ_t^2 and C_t/λ_t^3 (table 5 II)
In fig 6 8 it is shown for example how this change in C_t affects $M_s(z)$ $M_b(z)$ and p(z) as calculated with the beams on elastic foundation model described in paragraph 5 2

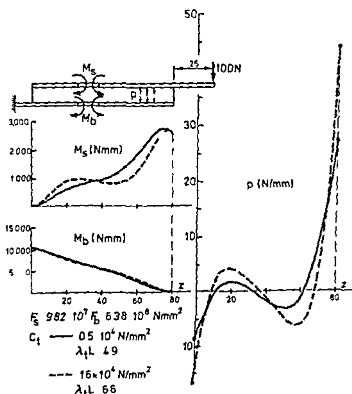


fig 6 8 Bending moments in stem and bone ($M_s(z)$ and $M_b(z)$) and distributed transverse load p(z) calculated using the beams-on elastic foundation model, for two different values of C_t simulating a fixed stem (C_t = 1 6x10^{4}N/mm^2) and a loose stem (C_t = 0 5x10^{4}N/mm^2)

It was shown that the loosening upon tension aspect of the stem cement interface has a moderate general effect on the mechanical behavior of the structure and an outspoken local effect mainly on the cement and interface stresses The general effect can be taken into account by adjusting the value of C_t and the local effect by interpreting the continuously distributed transverse load p(z) as working on half the stem circumference only If it is the object to evaluate the stress distribution in the cement layer and at the interfaces in detailed three dimensional FEM models the slip and loosening upon tension aspects should be taken into account Once this is done for the stem cement interface the conditions at the cement bone interface will not have much influence anymore

6 3 Nonconstant cross sectional properties of the stem

For the analyses discussed in chapter 5 it was assumed that the cross-sectional properties of the stem (F_s and P_s) were constant The stem may be tapered to some extent and since Young s modulus is constant, F_s and P_s will be functions of z as well as C_t and C_a It can be anticipated that for a slight taper the formulas derived in chapter 5 will still apply by approximation for a more pronounced taper this may not be so
When the dependencies of z in C_a and C_t are neglected in this case (neglecting dC_a/dz d^2C_a/dz dC_t/dz and d^2C_t/dz^2) the differential equations as in paragraph 5 2 can be formulated in the bending moments (M_s and M_b) and the axial forces (N_s and N_b) respectively so that the coefficients λ_t and λ_a still have significance this time however as functions of z
A first order evaluation of the taper influence can be established by regarding the influences on $\lambda_t(z)$ and $\lambda_a(z)$ Three different stem shapes are assumed (fig 6 11) in an example (axisymmetric structure) For λ_t and λ_a it can be found (taking C_t and C_a according to appendix B) that

$$\lambda_t = A_1\sqrt[4]{\left\{\frac{\rho}{1-\rho}\left(\frac{F_b}{F_s}+1\right)\right\}} \quad \text{and} \quad \lambda_a = A_2\sqrt{\left\{\frac{-1}{\ln\rho}\left(\frac{P_b}{P_s}+1\right)\right\}}$$

where $\rho = r_s/r_b$ and A_1 and A_2 are constants depending on E_c ν_c E_b the bone dimensions and the interface conditions

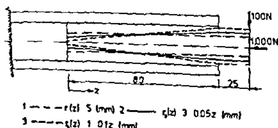


fig 6 11 The three different stem shapes investigated with the FEM beam model

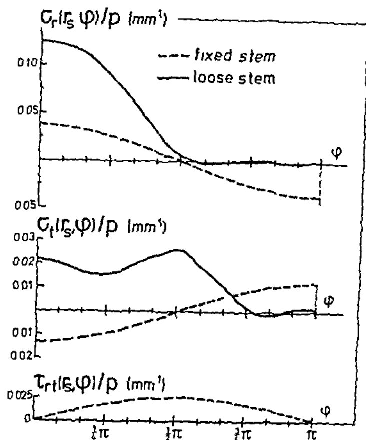


fig 6 10 Radial, circumferential and shear stress distribution on half the circumference of the stem cement interface, as calculated using FEM in a slice of the structure, for a loose stem and a fixed stem (Huiskes and Schouten, 1979) The stress components are given as relative to the local value of the transverse load p(z) The noise in the curves of the stresses in the case of a loose stem is caused by the solution procedure (Fourier expansion)

assumed to be loose in addition which could be concluded also from the results discussed in paragraph 6 2 1

6 2 4 *Conclusions*

In reality the interface conditions will be more complicated Friction will most certainly occur and locked in stresses may also be present, at least directly postoperatively Even in the idealized axisymmetric model discussed here the interface behavior is nonlinear because in principle the contact area changes with the load *For a loose stem no initial* locked in stresses, assuming a contact area over half the stem circumference results in a *reasonable approximation of the stress distribution (Schoofs 1979) In the case that locked* in stresses are present, the non linear effect will be more pronounced In this case that will occur during the initial postoperative period a C_t value in accordance with a fixed stem is *an upper boundary and one in accordance with a loose stem a lower boundary for the* apparent cement layer stiffness

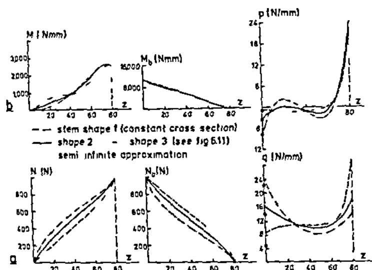


fig 6.13 *Continuously distributed shearing load q (z), stem and bone axial forces $N_s(z)$ and $N_b(z)$ on axial loading (a) and continuously distributed transverse load p(z), stem and bone bending moments $M_s(z)$ and $M_b(z)$ on transverse loading (b), as calculated using the FEM beam model for the three stem shapes Also indicated are the values for q(0) and p(0) (distal side), as calculated with the semi-infinite approximation, using the local stem radius in the formulas*

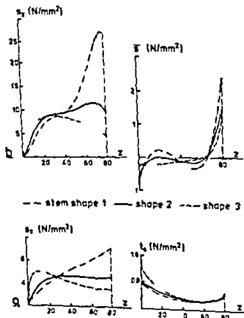


fig 6.14 *Stem and cement stresses on axial loading (a) and on transverse loading (b) as calculated for the three stem shapes*

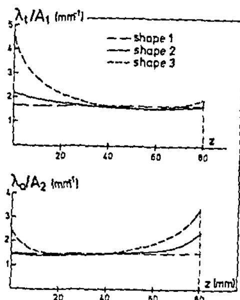


fig 6 12 The coefficients λ_t and λ_a as functions of z for the three stem shapes (for the constants A_1 and A_2 see text)

For the tapers shown in fig 6 11 the courses of λ_t/A_1 and λ_a/A_2 as functions of z were evaluated, as shown in fig 6 12 It can be anticipated, looking at these graphs, that in transverse loading there will be little difference in the mechanical behavior of the structure on the proximal side, but a significant difference on the distal side, especially where the pronounced taper is concerned In axial loading there should be little difference for the moderate taper compared to the constant cross sectional shape on the distal side and some difference on the proximal side, there should be a marked difference for the pronounced taper compared to the constant shape

Nonconstant cross sectional properties of the structure can be taken into account in the FEM beam model, as described in paragraph 5 4 This model was used to calculate p(z) q(z), $M_s(z)$ $M_b(z)$, $N_s(z)$ and $N_b(z)$ for the examples shown in fig 6 11 Results are shown in fig 6 13 It follows from these graphs, on consideration of the courses of p(z) and q(z), that the predictions expressed previously are fulfilled Nevertheless the difference in q(z) at the distal side for the moderate taper shape compared to the constant shape is somewhat more outspoken than anticipated Since in the case of the straight stem $\lambda_t L \approx 5\ 0$ and $\lambda_a L \approx 2\ 9$, this non predicted difference is probably caused by a significant influence from the proximal side on the distal side in axial loading (as discussed in paragraph 5 3 π/λ_a determines the length of the load introduction regions for axial loading)

It is also found that the maximal values of p(z) and q(z) on the distal side can be predicted by approximation with the formulas presented in table 5 II using the local value of r_s (respectively r_s = 5 3 and 2 mm) For transverse loading especially this approximation is excellent, as shown in fig 6 13 At the proximal side such an approximation does not succeed, probably owing to a stronger dependency of the stress variables on F_s and P_s (see table 5 II) and a higher sensitivity of C_t and C_a for the (varying) ratio ρ in this region because of the small thickness of the cement layer

Since the stem thickness varies, $M_s(z)$ $N_s(z)$, p(z) and q(z) are no longer proportional to the stem cement and cement stem interface stresses Representative of these stresses are the average transverse stress at the interface $\varsigma_{rs} = p/2r_s$ and the maximal axial stem stress $s_{zs} = M_s/W_s$ in transverse loading and the interface shear stress $t_s = q/\gamma_s$ and the maximal

in chapter 4 so that the varieties in F_b and P_b are probably not very pronounced Since the stem and the bone play analogue but inverse roles with respect to the proximal and distal sides the same kind of reasoning as for the nonconstant stem shape applies Also in this case the influences of arbitrary variations in z can be evaluated by using the FEM beam model

It is not known whether due to the trabecular bone in the epiphyseal regions of the bones d viations from beam theory might occur It is to be expected because as was shown in paragraph 5 1 in the schematized bone with homogeneous properties assumed deviations from beam theory already occurred (fig 5 5)
In for instance the proximal tibia this effect will be more pronounced than in the proximal femur since in the latter case cortical bone is present in the calcar region (on the medial side) where the greater part of the (transverse) load is introduced due to the loosening upon tension aspect of the stem cement interface
Due also to the epiphyseal spongeous bone which serves as an elastic layer the peak values in p(z) and q(z) could be lower and the load introduction somewhat smoother (smaller λ_t and λ_a) as indeed is apparent in the results from the three dimensional models of Scholten *et al* (1978) where non homogeneous bone properties are taken into account These effects can also be investigated by means of the FEM beam model
Apart from the inhomogeneous properties of the bone anisotropy was also neglected in the models as well as the slight curvatures of the stem and the bone It is expected that these phenomena will not affect the qualitative aspects of the model results

It has been shown in paragraph 5 2 that the formulas derived for the characterization of the mechanical behavior of the structure are valid for arbitrary cross-sections of the stem and the bone while for circular geometry examples were evaluated This means that the local influences of different stem cross-section geometries can be studied perfectly by modeling local sections as was done by Crowninshield and Branch (1978) For such studies the local loading can be derived from more general beams-on-elastic foundation or FEM beam analyses as discussed here

Effects that likewise were not taken into account here are those that may follow from the implantation procedure for instance incomplete cement mantles or from bone remodeling for example proximal bone resorption The influences of these effects could be roughly evaluated by applying the FEM beam model
Furthermore the effect of a collar on the proximal side of the hip-endoprosthesis stem (collar calcar contact see section I) has not been taken into account In all stress analyses reported in the literature this collar calcar contact is considered as beneficial which is hardly surprising since the loads (especially the axial load) will be introduced more directly to the cortex in a more natural way As follows directly from the analysis presented in paragraph 5 3 this will only influence the stresses in the proximal load introduction region and not in the middle and the distal regions as was also found by Crowninshield *et al* (1979) in their three-dimensional FEM model There appears to be enough evidence that collar calcar contact although present directly after surgery disappears upon load bearing post operatively due to (although mostly minor) bone resorption (see section I) Hence a collar has no significance for the long term performance of the bone prosthesis structure
When looking at the time factor in this respect it is evident (see also section I) that several effects tend to change the mechanical characteristics of the intramedullary fixation structure For example
early postoperative
– collar calcar contact (if a collar is present)

axial stem stress $s_{zs} = N_s/A_s$ in axial loading, as defined in paragraph 5 2 These stress quantities are shown in fig 6 14 for the three different stem shapes The courses of $s_{zs}(z)$ for the tapered stems are very much like the stem stresses that were measured by Huggler *et al* (1978) in strain gauge experiments on hip prostheses in cadaveric femurs, and the courses of $s_{zs}(z)$ $\bar{s}_{rs}(z)$ and $t_s(z)$ are comparable to results of three dimensional FEM models (e g Scholten *et al*, 1978) It should be noted that the stresses in the bone ($s_{zb}(z)$) and at the cement bone interface ($\bar{s}_{rb}(z)$ and $t_b(z)$) are directly proportional to $M_b(z)$ and $N_b(z)$, $p(z)$ and $q(z)$, respectively, since r_b remains constant Regarding figs 6 13 and 6 14 it is evident that the use of a tapered stem benefits the system performance In transverse loading the pronounced taper shows the best results, in axial loading the moderate taper In chapter 8 the stem shape will be further discussed

In the literature, composite beam theory is often used to evaluate the stresses in the stem (e g Bartel and Desormeaux, 1976a, Walker, 1977, Swanson and Freeman, 1977) As we have seen in paragraph 5 3 , this approximation is valid for the middle region of structures with constant cross section, if $\lambda_t L$ and $\lambda_a L$ are sufficiently large For tapered stems the approximation may be rather poor, as is illustrated in fig 6 15 for the moderately tapered stem

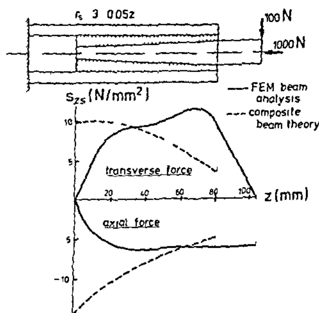


fig 6 15 A comparison of stem stresses on axial and transverse loading, as calculated for stem shape no 2 using the FEM beam model and composite beam theory, the latter method is in this case not very accurate

6 4 Other aspects

The cross sectional properties of the bone will vary, too as functions of z In the femur the outside dimensions increase from the diaphysis region to the proximal side Likewise the width of the medullar canal increases while more trabecular bone is present in the meta physis (with a lower Young s modulus) compared to the diaphysis region The varieties in the geometrical and material stiffness however work in opposite directions as was discussed

Likewise the coefficient λ_w in torsion that determines the lengths of the proximal and distal regions has the same form as λ_a in axial loading For $\rho = 0\ 5$ it follows (assuming the *reference values as discussed in chapter 3 for the other parameters)* that $\lambda_a \approx 0\ 04\ mm^{1}$ and $\lambda_w \approx 0\ 06\ mm^{1}$ for $\rho = 0\ 8$ $\lambda_a \approx 0\ 05\ mm^{1}$ and $\lambda_w \approx 0\ 08\ mm^{1}$

In conclusion the proximal and distal regions will be shorter in torsional loading compared to axial loading and qualitatively speaking the same tendencies that are found for axial loading apply to torsional loading

It should be remarked here that one should be rather careful with these formulas for torsional loading since they have not been verified in a FEM analysis

Furthermore especially for non circular geometries the mechanical behavior of the structure may be quite complicated in torsion

- thermal locked in stresses (initial stresses, no loosening upon tension at the cement stem interface),

later postoperative

- no collar calcar contact,
- no thermal locked in stresses (*loosening upon tension, hence a lower* C_t value for the cement mantle, decreased λ_t, less friction),
- osteoporosis (decreasing F_b and P_b hence increasing λ_t and λ_a),

late postoperative

- calcar resorption (increased free stem length, reduced fixation length),
- further osteoporosis (decreasing F_b and P_b, increasing λ_t and λ_a, especially at the proximal side),
- cement ageing (reduced E_c, reducing C_a and C_t, λ_a and λ_t),
- *fibrous tissue layer at the cement bone interface*

An interesting investigation would be to follow such processes and roughly quantify the effects of the changes on the stress distribution in the structure For such a study the analytical concepts and the FEM beam model developed here can be used combined with radiographical or (in animal studies) histological data

Another aspect that has been neglected here, and indeed has received little attention in orthopedic biomechanics literature, is the incidence of torsion on the stem Torsion will occur in the artificial hip joint, as was shown for instance by Rydell (1966) (see section 1) and will even be the most important loading case in the elbow joint For a first order evaluation of the effect of torsional loading the axisymmetric model can again be used Also in this case the Winkler hypothesis can be applied to the cement layer Its stiffness is then represented by a continuous set of linear torsional springs The mechanical behavior of the structure in torsion is described by torsional moments in the stem and the bone and by a continuously distributed shearing moment at the interfaces (Nmm/mm), as functions of z Here, too the stiffness of the cement mantle can be approximated by a stiffness factor comparable to C_a in axial loading If the differential equations are formulated in the tangential displacements of the outer stem and the inner bone circumferences, they are found to be completely analogous with those of the axial loading case, boundary conditions included Hence the solutions are identical, except for the expressions of the stiffness factors A comparison of stem, bone and cement stiffness factors is shown in table 6 1

	axial loading		torsional loading		
cement mantle (C_a in axial loading)	$-\frac{\pi E_c}{(1+\nu_c)\ln\rho}$	(N/mm²)	$\frac{\pi \rho E_c r_b}{(1-\rho)(1+\nu_c)}$	(1)	(N/mm)
stem (P_s in axial loading)	$\pi r_s^2 E_s$	(N)	$\frac{\pi E_s r_s^3}{4(1+\nu_s)}$		(Nmm)
bone (P_b in axial loading)	$\pi E_b(r_o^2 - r_b^2)$	(N)	$\frac{\pi E_b(r_o^4 - r_b^4)}{4r_b(1+\nu_b)}$		(Nmm)

table 6 1 Structural stiffness factors of the stem the bone and the cement mantle (axisymmetric model) in torsional loading compared to those for axial loading (1) reasonable approximation when ρ is sufficiently close to 1

Likewise the coefficient λ_w in torsion that determines the lengths of the proximal and distal regions has the same form as λ_a in axial loading For $\rho = 0\ 5$ it follows (assuming the ref rence values as discussed in chapter 3 for the other parameters) that $\lambda_a \approx 0\ 04\ mm^{-1}$ and $\lambda_w \approx 0\ 06\ mm^{-1}$ for $\rho = 0\ 8$ $\lambda_a \approx 0\ 05\ mm^{-1}$ and $\lambda_w \approx 0\ 08\ mm^{-1}$
In conclusion the proximal and distal regions will be shorter in torsional loading compared to axial loading and qualitatively speaking the same tendencies that are found for axial loading apply to torsional loading
It should be remarked here that one should be rather careful with these formulas for torsional loading since they have not been verified in a FEM analysis
Fu thermore especially for non circular geometries the mechanical behavior of the structure may be quite complicated in torsion

CHAPTER SEVEN

THE INFLUENCES OF THE ESSENTIAL PARAMETERS

7 1 Premises

The influences of the essential parameters on the mechanical behavior of the bone prosthesis structure can be evaluated with the formulas derived in paragraph 5 3 (see table 5 II) and by applying parametric analysis, using the other models discussed in chapter 5
For reasons of convenience, the factors in the formulas of table 5 II are denoted as follows

proximal region $\alpha_m = \frac{1}{2}\frac{C_t}{\lambda_t^2 F_s}$, $\alpha_t = \frac{1}{2}\frac{C_t}{\lambda_t^3 F_s}$, $\alpha_n = \frac{\lambda_a P_b}{P_s + P_b}$,

distal region $\beta_m = \frac{1}{2}\frac{C_t}{\lambda_t^2 F_b}$ $\beta_t = \frac{1}{2}\frac{C_t}{\lambda_t^3 F_b}$, $\beta_n = \frac{\lambda_a P_s}{P_s + P_b}$,

middle region $\epsilon_m = \frac{F_s}{F_s + F_b}$, $\epsilon_n = \frac{P_s}{P_s + P_b}$,

where λ_t and λ_a can be evaluated from

$$\lambda_t = \sqrt[4]{\left\{\frac{C_t}{4}\left(\frac{1}{F_s} + \frac{1}{F_b}\right)\right\}} \quad \text{and} \quad \lambda_a = \sqrt{\left\{C_a\left(\frac{1}{P_s} + \frac{1}{P_b}\right)\right\}}$$

Using these two expressions, the factors α_m through ϵ_n can be rewritten as functions of C_t, C_a F_s F_b P_s and P_b only
These forms are valid for arbitrary cross sectional geometry, C_a and C_t can be approximated using the formulas presented in appendix B
Using the factors defined above the stress variables for the proximal distal and middle regions as defined in paragraph 5 3 , can be expressed as shown in table 7 I these stresses are once more illustrated in fig 7 1 By considering these formulas and the expressions for the factors α_m through ϵ_n (taking the expressions for λ_t and λ_a into account) the influences of the structural parameters on the most important stresses can be directly evaluated
In table 7 II these influences are given qualitatively

In the following paragraphs the parameter influences are discussed separately, mainly using the formulas but also as follows from parametric analyses with the other models

7 2 The stem length

The length of the stem, together with the values of λ_t and λ_a, determine whether the proximal and distal stresses influence each other and whether there is a middle region that behaves approximately in accordance with composite beam theory

stress component	proximal region (z = L)	distal region (z = 0)
$s_{zs} = \frac{M_s}{W_s} + \frac{N_s}{A_s}$	$\frac{M_L}{W_s} + \frac{N_L}{A_s}$	0
$\bar{s}_{rs} = \frac{p}{2r_s}$	$\frac{\alpha_m}{2r_s} M_L + \frac{\alpha_t}{2r_s} T_L$	$-\frac{\beta_m}{2r_s}(M_L + T_L L) + \frac{\beta_t}{2r_s} T_L$
$\bar{s}_{rb} = \frac{p}{2r_b}$	$\frac{\alpha_m}{2r_b} M_L + \frac{\alpha_t}{2r_b}$	$-\frac{\beta_m}{2r_b}(M_L + T_L L) + \frac{\beta_t}{2r_b} T_L$
$t_s = \frac{q}{\gamma_s}$	$-\frac{\alpha_n}{2\pi r_s} N_L$	$-\frac{\beta_n}{2\pi r_s} N_L$
$t_b = \frac{q}{\gamma_b}$	$-\frac{\alpha_n}{2\pi r_b} N_L$	$-\frac{\beta_n}{2\pi r_b} N_L$
middle region	$s_{zs} = \frac{M_s}{W_s} + \frac{N_s}{A_s} = \frac{\epsilon_m}{W_s}(M_L + T_L(L-z)) + \frac{\epsilon_n}{A_s} N_L$	

table 7 I Approximative formulas describing the most important stress variables in the stem the bone in the cement layer and at the interfaces in the proximal middle and distal regions respectively (see also table 5 II and fig 7 1)

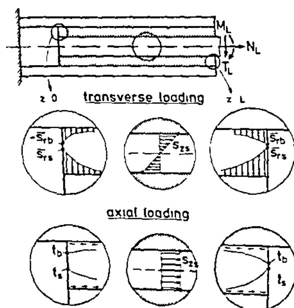


fig 7 1 An illustration of the stress components in the stem the bone the cement and at the interfaces on transverse and axial loading as described by the approximative formulas

	C_t	F_s	F_b	C_a	P_s	P_b
proximal						
α_m	+	—	+	o	o	o
α_t	+	—	+	o	o	o
α_n	o	o	o	+	—	+
distal						
β_m	+	+	—	o	o	o
β_t	+	+	—	o	o	o
β_n	o	o	o	+	+	—
middle						
ϵ_m	o	+	—	o	o	o
ϵ_n	o	o	o	o	+	—

table 7 II Qualitative influences of the single characteristic structural parameters on the factors α, β and ϵ, for (+) the factor increases with increasing parameter value, for (—) it decreases, for (o) there is no influence

It should be kept in mind that, generally speaking the stresses at the proximal and distal sides are lower when they do not influence each other and that the middle region serves no purpose in the prosthesis bone load transmission

For values of approximately $\lambda_t L \gtrsim \pi$ and $\lambda_a L \gtrsim \pi$ there is little influence from the distal on the proximal side and vice versa This means also, that when the stem length is extended beyond $L \approx \pi/\lambda_t$ and $L \approx \pi/\lambda_a$, this has very little influence on the stresses in the structure resulting from the respective loading cases However, there is one exception as shown in tables 5 II and 7 I, L appears in the formulas for the distal stresses ($p(0)$ $s_{rs}(0)$ and $s_{rb}(0)$) and the stem stresses in the middle region ($s_{zs}(z)$) as a coefficient of T_L the transverse force Hence, for this loading case it is of importance to keep the length restricted, a more or less optimal value would then be $L \approx \pi/\lambda_t$

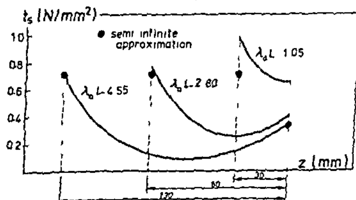


fig 7 2 Shear stress at the stem-cement interface on axial loading as calculated using the beams-on elastic foundation theory, for three different lengths of the stem Also indicated are the values for q(0) and q(L) as calculated using the semi infinite approximation, which is appropriate when $\lambda_a L$ is sufficiently high

Fig 7 2 gives an example of $t_s(z)$ upon axial loading as calculated for three different stem lengths using the beams-on-elastic foundation theory described in paragraph 5 2 2 the values that result from the semi infinite theory using the formulas of table 7 1 are also shown It is evident that for L > 80 mm extending the length has little effect on the maximal stress values As follows again from fig 7 2 the semi infinite approximation is better for the longer stems

Fig 7 3 shows an example of the courses of $M_s(z)$ $M_b(z)$ and $p(z)$ upon transverse loading for three different stem lengths as calculated with the theory described in paragraph 5 2 1 *It should be noted that* a dimensionless coordinate (z/L) is used on the horizontal axis Extending the length from 80 to 130 mm has no effect on the proximal stresses and a negative effect on the distal cement stresses and the stem stresses due to the previously described *influence* of T_L In this case too the semi infinite approximations of p(0) and p(L) are indicated in the figure

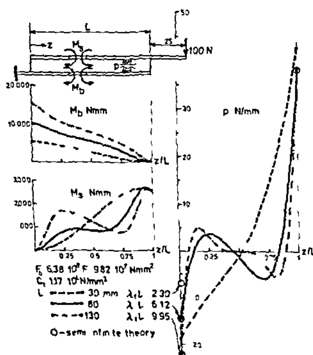


fig 7 3 Bending moments in the stem and the bone ($M_s(z)$ and $M_b(z)$) and the continuously distributed transverse load p(z) as calculated with the beams-on-elastic foundation theory for three different stem lengths Note that, in this case, z/L is put on the horizontal axis The values for p(0) and p(L) as calculated with the approximative formulas are also indicated For the very short stem these formulas no longer apply very accurately

The influences discussed above are confirmed for other stress components as well when the three-dimensional FEM model is used to analyze the effect of the stem length as was shown in Huiskes *et al* (1977) As discussed in chapter 5 the stem and bone stresses are quite accurately described in the beams-on-elastic foundation models but several stress components

in the cement layer are neglected These components show the same tendencies as the ones discussed above, as for example is shown in fig 7 4 as regards the hoop stress (σ_t), the axial stress (σ_z) and the shear stress (τ_{rz}) in transverse loading

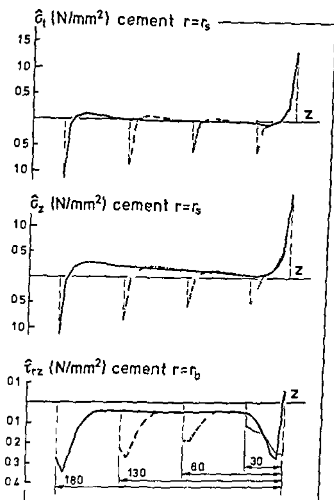


fig 7 4 Hoop stresses and axial stresses in the cement layer at the stem cement interface and shear stresses at the cement bone interface as calculated with the three-dimensional FEM model, on transverse loading, for four stem lengths

7 3 The structural stiffness of the cement mantle

The factors α_m and β_m are proportional to $\sqrt{C_t}$ α_t and β_t to $\sqrt[4]{C_t}$ and α_n and β_n to $\sqrt{C_a}$ Hence, all important cement and interface stresses will decrease with decreasing C_t and C_a Also, λ_t and λ_a are influenced by C_t and C_a respectively In general it can be said that the load introduction at the proximal and distal sides will be smoother for lower values of C_t and C_a

Fig 7 5 shows an example of values for $M_s(z)$ $M_b(z)$ and $p(z)$ on transverse loading as calculated for three values of C_t, using the beams on elastic foundation theory The decrease in the proximal and distal maximal values of $p(z)$ on decreasing C_t is apparent The stresses in the stem are only slightly influenced Owing to the decreasing value of λ_t with decreasing C_t the middle region is shortened The same effects are apparent in axial loading For low C_a the shear stresses will tend to be smoothened towards a constant value over the length of the

structure There is only a minor influence on the stem and the bone stresses in this case, too

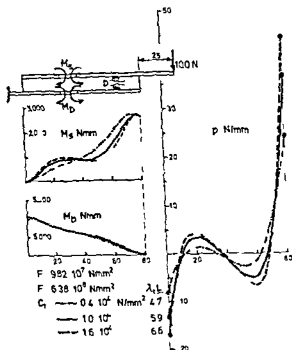


fig 7 5 $M_s(z)$ $M_b(z)$ and $p(z)$ as calculated with the beams-on-elastic foundation theory for three different values of C_t keeping the other parameters (F_s, F_b and L) constant

C_t and C_a depend on the thickness the Young s modulus and the Poisson s ratio of the cement layer The layer thickness depends on the dimensions of the stem and the bone which will be discussed later C_t and C_a are directly proportional to E_c C_t is by approximation proportional to $(1-\nu_c)/(1+\nu_c)(1-2\nu_c)$ (appendix B) for $0.2 \lesssim \nu_c \lesssim 0.4$ this factor varies from approximately 1 1 to 2 1 C_a is by approximation proportional to $1/(1+\nu_c)$ which varies from only 0 8 to 0 7 in the above mentioned range Hence overall a low value of ν_c is advantageous

These effects were again confirmed for other stress components as well with the three dimensional FEM model (Huiskes 1977 Huiskes and Slooff 1978) Only in one respect did this model give additional information the value of ν_c *has a marked influence* on the axial and hoop stresses in the cement mantle as shown in fig 7 6

7 4 The structural stiffness of the stem

The structural stiffness of the stem expressed in F_s and P_s depends on its material stiffness (Young s modulus) and its geometrical stiffness (cross sectional area and second moment of inertia) Higher values of F_s and P_s will reduce λ_t and λ_a so that the proximal and distal load introduction regions will be extended

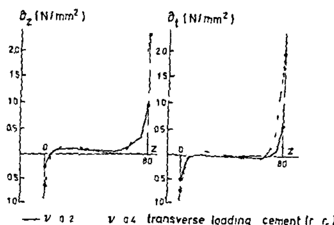


fig 7 6 Axial and hoop stresses in the cement at the stem-cement interface, on transverse loading, as calculated with the three dimensional FEM model for two different values of ν_c

The values of α_m α_t and α_n will also decrease, causing p(L) and q(L) (proximal side) to decrease, β_m β_t β_n ϵ_m and ϵ_n will increase as a result of which p(0) and q(0) (distal side) $M_s(z)$ and $N_s(z)$ (middle region) increase This is illustrated in fig 7 7 for transverse loading where $M_s(z)$ $M_b(z)$ and p(z) are shown as calculated for three values of F_s using the beams on elastic foundation model Apparently p(L) is more sensitive to F_s than p(0) due to the fact that β_m, for example is approximately proportional to $\sqrt{F_s}$ and α_m to $1/F_s$

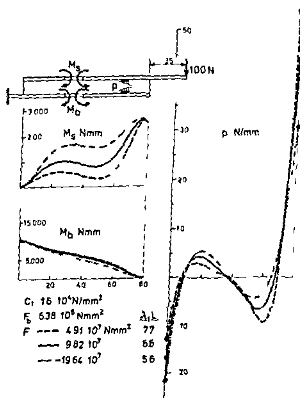


fig 7 7 $M_s(z)$, $M_b(z)$ and p(z) on transverse loading, as calculated with the beams-on-elastic foundation theory for three different values of F_s, keeping the other parameters (F_b, C_t and L) constant

Changing F_s and P_s without affecting other parameters is only possible by changing E_s. In this case the structure will be influenced purely as described above. This was again confirmed for other stress components in the cement on application of the three-dimensional FEM model (Huiskes 1977; Huiskes and Slooff, 1978).
When the thickness of the stem is changed, apart from the influences on F_s and P_s, two other effects play a role: the thickness of the cement layer changes, hence C_a and C_t are influenced, and the load transferring area of the stem cement interface (represented by r_s) changes, which has a local effect on the stresses. At the proximal side the first effect (F_s and P_s) and the last effect (r_s) combine to decrease or increase the stresses, but the second effect (C_t and C_a) works in the opposite direction. At the distal side the first effect (F_s and P_s) and the second effect (C_t and C_a) combine to decrease or increase the stresses, but the third effect (r_s) works in the opposite direction. In the middle region C_t and C_a have little influence on the stem stresses, the other two effects work in opposite directions. Hence optimal values for the stem thickness in the different regions should be expected to exist.
For circular geometry these effects are evaluated in the figs. 7.8 through 7.10 as the influences of the stem radius on the factors α and β. It is evident that on the distal side the stem should, for all stress components, be as thin and flexible as possible. On the proximal side the stem material should be as stiff as possible; for the stem thickness, however, there is an optimum value, that in this case (the chosen bone properties) is $r_s \approx 8$–9 mm (layer thickness of 1–2 mm) on transverse loading and $r_s \approx 6$–8 mm (layer thickness of 2–4 mm) on axial loading.

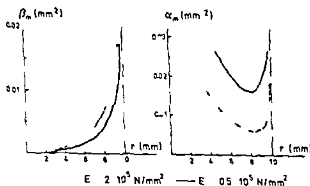


fig. 7.8 *The factors α_m and β_m as functions of r_s (circular geometry) for two different values of E_s.*

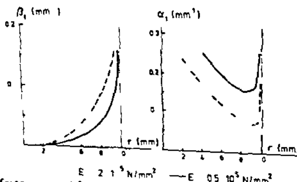


fig. 7.9 *The factors α_t and β_t as functions of r_s (circular geometry) for two different values of E_s.*

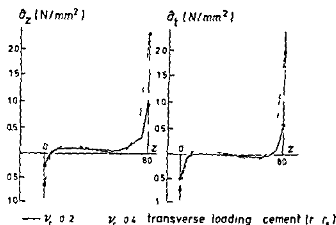


fig 7 6 Axial and hoop stresses in the cement at the stem-cement interface, on transverse loading, as calculated with the three dimensional FEM model for two different values of ν_c

The values of α_m α_t and α_n will also decrease, causing p(L) and q(L) (proximal side) to decrease, β_m β_t β_n ϵ_m and ϵ_n will increase as a result of which p(0) and q(0) (distal side), $M_s(z)$ and $N_s(z)$ (middle region) increase This is illustrated in fig 7 7 for transverse loading where $M_s(z)$ $M_b(z)$ and p(z) are shown as calculated for three values of F_s using the beams on elastic foundation model Apparently p(L) is more sensitive to F_s than p(0) due to the fact that β_m for example is approximately proportional to $\sqrt{F_s}$ and α_m to $1/F_s$

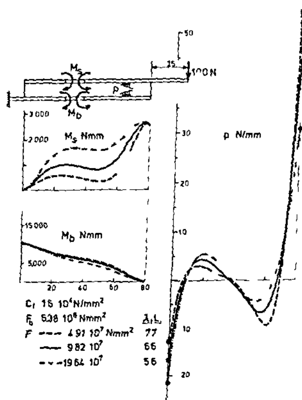


fig 7 7 $M_s(z)$, $M_b(z)$ and $p(z)$ on transverse loading, as calculated with the beams-on elastic foundation theory for three different values of F_s keeping the other parameters (F_b C_t and L) constant

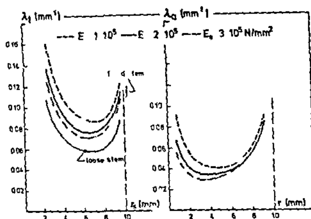


fig 7 11 The coefficients λ_t and λ_a as functions of r_s (circular geometry) for different values of E_s

7 5 The structural stiffness of the bone

As regards the mechanical behavior of the structure the roles of F_b and P_b are equivalent to those of F_s and P_s but inversed at the proximal and distal sides When E_b and r_p change only F_b and P_b are affected Higher values of F_b and P_b will reduce λ_t and λ_a respectively so that the proximal and distal load-introduction regions will be extended The values of α_m α_t and α_n will increase causing p(L) and q(L) (proximal region) to increase β_m β_t β_n ϵ_m and ϵ_n will decrease as a result of which p(0) and q(0) (distal region) and $M_s(z)$ and $N_s(z)$ (middle region) decrease

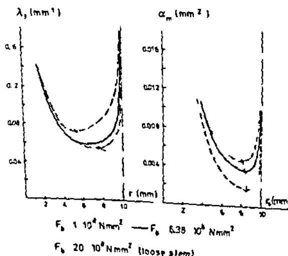


fig 7 12 The coefficient λ_t and the factor α_m as functions of r_s (circular geometry) for three different values of F_b

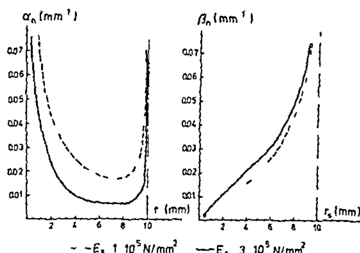


fig 7 10 The factors α_n and β_n as functions of r_s (circular geometry), for two different values of E_s.

The values of r_s for which the minima in α_m α_t and α_n occur are independent of E_c, ν_c and the interface conditions As follows from figs 7 8 through 7 10, they are not very sensitive for the stem Young's modulus too Since the factors $-1/\ln\rho$ and $\rho/(1-\rho)$ (on which C_a and C_t depend) are rather strong for ρ close to 1, the locations of the minima will thus be determined by r_b-r_s (the layer thickness), rather than by the stem thickness itself Hence the optimal values for the layer thickness mentioned above can probably be regarded as generally applicable It should be remarked, however, that in this case the presence of a soft bone layer (spongeous bone) was not taken into account

In the middle region the stem stresses decrease for a thicker stem on axial loading On transverse loading the stem stresses will be lower for a thin stem as well as for a very thick stem, for circular geometry a maximum occurs for $r_s = \sqrt[4]{(16F_b/3\pi E_s)}$ For both the transverse and axial loading cases the stem stresses decrease on decreasing Young s modulus of the stem material On transverse loading the stem stresses are almost proportional to the modulus, on axial loading the influence is somewhat less pronounced

The thickness of the stem also affects the coefficients λ_a and λ_t Here too the effects of the changes in the stem stiffness and the cement mantle stiffness work in opposite directions, hence minimal values for λ_a and λ_t exist
For circular geometry the influences of the stem thickness (r_s) on the values of λ_a and λ_t are shown in fig 7 11

In a cross section of the structure the total bending moment and the total axial force follow from

$$M(z) \approx M_s(z) + M_b(z) \quad \text{and} \quad N(z) \approx N_s(z) + N_b(z)$$

In using these formulas the influence of the structural stiffness of the stem on the bone stresses can directly be evaluated if the effect on the stem stresses is known

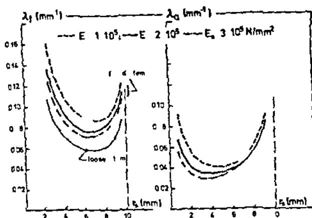


fig 7 11 The coefficients λ_t and λ_a as functions of r_s (circular geometry) for different values of E_s.

7 5 The structural stiffness of the bone

As regards the mechanical behavior of the structure the roles of F_b and P_b are equivalent to those of F_s and P_s, but inversed at the proximal and distal sides When E_b and r_o change only F_b and P_b are affected Higher values of F_b and P_b will reduce λ_t and λ_a respectively so that the proximal and distal load-introduction regions will be extended The values of α_m α_t and α_n will increase causing p(L) and q(L) (proximal region) to increase β_m β_t β_n ϵ_m and ϵ_n will decrease as a result of which p(0) and q(0) (distal region) and $M_s(z)$ and $N_s(z)$ (middle region) decrease

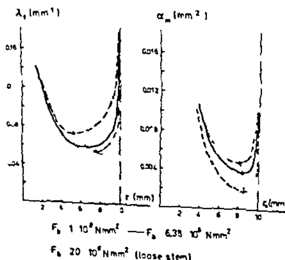


fig 7 12 The coefficient λ_t and the fa tor α_m as functions of r_s (circular geometry) for three different values of F_b.

For circular geometry the influences of F_b on $\lambda_t(r_s)$ and $\alpha_m(r_s)$ are shown in fig 7 12, assuming a constant inner bone radius (r_b) and constant stem and cement materials properties Apparently the value of r_s for which the minimum in α_m occurs is not very sensitive for F_b also

If r_b changes then the cement layer thickness also changes In this case it can be expected, as discussed in paragraph 7 4 , that a layer thickness of around 2 mm will still be an optimum where the stresses at the proximal side are concerned

These tendencies were again confirmed by the results of the three-dimensional FEM model (Huiskes, 1977) Fig 7 13 shows an example of stem, cement and bone equivalent stresses on transverse and axial loading for two different Young's moduli of the bone

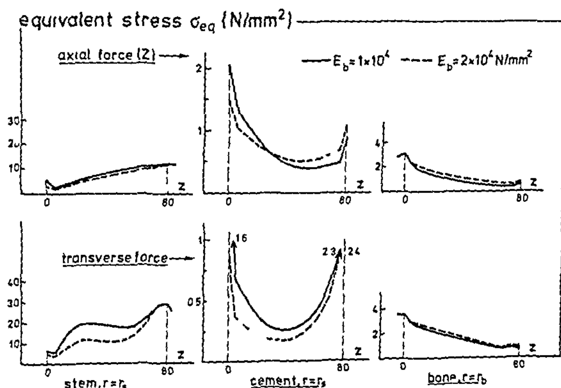


fig 7 13 Equivalent stresses in stem, bone and cement (at the stem-cement interface) on axial loading and transverse loading as calculated with the three dimensional FEM model, for two different values of E_b.

CHAPTER EIGHT

GUIDELINES FOR STEM DESIGNS AND IMPLANTATION PROCEDURES

In the previous chapter the influences of the characteristic parameters of the structure on its mechanical behavior were studied It was shown that the analytical models described in chapter 5 could conveniently be used for these parametric analyses and that by using the approximative formulas practically all influences could be evaluated The results of the three-dimensional FEM model that are more detailed especially where the cement layer is concerned confirmed the tendencies found Only with respect to the influence of ν_c on axial and hoop stresses did the FEM model give information that could not be provided by the analytical models
From the concepts developed in the previous chapters some guidelines for stem designs and implantation procedures can be derived, as will be discussed in this chapter

It was shown that all cement and interface stresses are reduced by using an intermediate layer of low Young s modulus and Poisson s ratio It should be borne in mind however that a material with a low modulus usually also has low strength properties Silastics for instance have a low modulus but are not very strong and almost incompressible (high Poisson s ratio) which makes them rather unsuitable for use as intermediate material Obviously in the case of acrylic cement its quality should be optimal From a mechanical point of view the use of an intramedullary plug cleansing before cement insertion and inserting under pressure (see section 1) would therefore be advantageous

In order to reduce the cement and interface stresses at the distal side the stem length should be kept restricted An adequate length is the one for which the proximal and distal sides are approximately independent in their mechanical behavior a length that is determined by the coefficients λ_a and λ_t These depend on the structural stiffness of the stem the bone and the cement layer that is on the material and geometrical characteristics of the stem the bone and the intermediate layer This implies for instance that a titanium alloy stem will require a different length compared to a cobalt chromium steel alloy stem but also that patients with tiny or osteoporotic bones require stems of different length compared to patients with heavy or dense bones No doubt an indication of the bone quality can be obta ned from pre-operative roentgenograms If stems of different sizes were available the best fitting stem for a specific patient could be chosen pre operatively by using the concepts presented here

On the proximal side the stem should be thick and the material stiff in order to reduce the cement and interface stresses in this region A cement layer of about 2 mm should be retained however and this again implies a more custom fit approach measuring the bone dimensions pre-operatively and choosing an implant from different sizes available
On the distal side the stem should be thin and flexible The requirements for the proximal and distal sides can only be met by using a tapered stem The geometry of the taper can be studied by using the FEM beam model as will be shown in the following example In this example the choice of materials for the stem entailing conflicting influences on the proxi mal region and the distal and middle regions will also be discussed In order to reduce the stem stresses in the middle region the stem should be thick and its material flexible

However the middle region serves no specific purpose in the load transmission process from implant to bone and should be kept restricted as much as possible The effect of the taper shape on the stem stresses will also be discussed in the following example

A specific bone of given properties is assumed (axisymmetric, r_b = 10 mm, r_o = 15 mm E_b = 2x10^4 N/mm^2) For this bone an adequate stem design will be developed, as an example, using the concepts and methods presented previously
In the proximal region the stem should be as thick as possible, leaving a layer thickness of 2 mm, so that r_s = 8 mm at the proximal side In the first instance the stem material is taken as Co Cr steel (E_s = 2x10^5 N/mm^2) The Young's modulus of the cement is taken as E_c = 2x10^3 N/mm^2, its Poisson's ratio as ν_c = 0 33
In accordance with the results presented in paragraph 6 2, the stem is assumed to loosen upon tension from the cement layer The resulting values for the mechanical characteristics of the proximal side a e shown in table 8 I

parameter	unit	value	parameter	unit	value
F_s	Nmm^2	6 43x10^8	P_s	N	4 02x10^7
F_b	Nmm^2	6 38x10^8	P_b	N	7 85x10^6
C_t	N/mm^2	1 79x10^4	C_a	N/mm^2	2 12x10^4
λ_t	mm^{-1}	6 11x10^{-2}	λ_a	mm^{-1}	5 68x10^{-2}

table 8 I Values for the characteristic parameters at the proximal side

The length of the proximal side (L_{pr}) is chosen in such a way that the initial load introduction effects are damped out in this region using the criterion $\lambda_t L_{pr} \gtrsim \pi/2$ or $\lambda_a L_{pr} \gtrsim \pi/2$ as discussed in paragraph 5 3 From this it follows $L_{pr} \geq$ 27 7 mm we took L_{pr} = 30 mm As shown in the previous chapter the distal end of the stem should be thin and flexible, for the extreme distal stem radius we taken r_s = 1 mm Between the distal tip and the end of the proximal region a certain tapered shape has to be designed To determine the length of this part of the stem (L_t), λ_a is used in the first instance, because $\lambda_a < \lambda_t$ As shown in fig 7 11 λ_a varies approximately between 0 060 and 0 035 mm^{-1} for $1 \leq r_s \leq 4$ mm, and between 0 035 and 0 057 mm^{-1} for $4 \leq r_s \leq 8$ mm Taking an approximate average value it follows (with the criterion $\lambda_a L_t \gtrsim \pi/2$) that $L_t \geq$ 35 mm we take L_t = 40 mm to start with This taper shape, and two longer ones (60 and 80 mm) are analysed as to their mechanical performance in the given bone, using the FEM beam model
Fig 8 1 shows an example of results stem cement interface stresses $\bar{s}_{rs}(z)$ and stem stresses $s_{zs}(z)$ on transverse loading stem cement interface shear stresses $t_s(z)$ and stem stresses $s_{zs}(z)$ on axial load ng Apparently the taper length of 40 mm has been a good choice where the length of the distal introduction region is concerned but on transverse loading this stem tip is still too stiff For L_t = 60 mm the stem stresses are somewhat higher, but the distal cement stresses are considerably lower By extending the taper length to 80 mm nothing is gained Taking L_t = 60 mm two other stem shapes are investigated as shown in fig 8 2
It is remarkable considering $\bar{s}_{rs}(z)$ in fig 8 2, that such a seemingly slight difference as between shapes 1 and 2 has so much effect in transverse loading. It should be noted too that the stresses on the proximal side do not differ significantly (as is also evident in fig 8 1) because the length of the proximal region was chosen in such a way that both ends of the stem will not influence each other

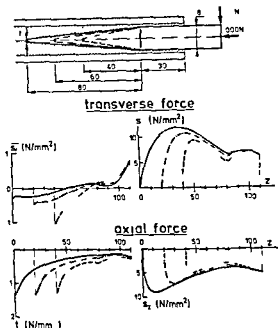


fig 8 1 Stem stresses and stem-cement interface stresses in axial and transverse loading as calculated with the FEM beam model for three different stem taper lengths

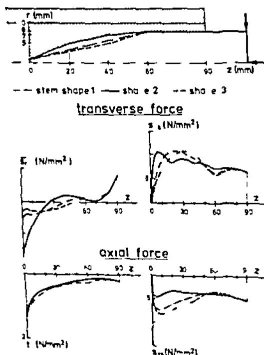


fig 8 2 Stem stresses and stem-cement interface stresses in axial and transverse loading as calculated with the FEM beam model for three different stem shapes (1 2 and 3) Some of the curves (especially s_{zs}) are not smooth due to the abrupt changes in the stem taper

Shape 3 is chosen as the best one in this case although there is little difference between 1 and 3 Of course, in reality the abrupt transitions in the taper would have to be somewhat rounded off

Using this shape, the materials choice is further investigated The Young s modulus of the stem is taken as $3x10^5$ N/mm² (simulating ceramics), $2x10^5$ N/mm² (simulating Co-Cr steel) and $1x10^5$ N/mm² (simulating titanium), respectively Some results are shown in fig 8 3 The important aspects of these results can of course be predicted using the approximative formulas As is evident when regarding fig 8 3, the use of ceramics would be *advantageous for the proximal cement and interface stresses only, while the use of titanium* would be advantageous for all but these stresses (in this case the axial bone stresses are *somewhat more natural in addition) Co Cr steel appears to be a reasonable compromise* However, if the thickness of the proximal titanium stem could be increased by approximately 20%, while retaining a layer thickness of 2 mm, the proximal cement and interface stresses would be approximately equal to or lower than those for the Co Cr steel stem in the example, as follows from the formulas for F_s and P_s

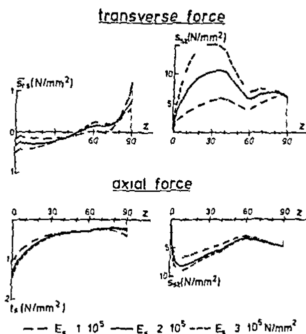


fig 8 3 Stem stresses and stem cement interface stresses in axial and transverse loading, as calculated with the FEM beam model for stem shape no 3 and three different values of Young s modulus of the stem, simulating Co Cr steel, titanium and ceramics
(For ceramics E_s = $3x10^5$ N/mm² was taken, in reality this value will even be about 30% higher)

It is thus evident that a stem design should (and can) be adapted to the materials applied For instance in the literature iso elastic prostheses are being considered (Morscher *et al* 1976) The apparent elasticity of this (porous) material is approximately equal to that of bone ($E_s \approx 0\,2x10^5$) The use of this material will reduce all important stresses except in *the proximal cement* The cement and interface stresses in this region would be increased by more than 200% in comparison to Co-Cr alloys *which is unacceptable A solution can be* found in the application of a proximal stiffener a steel tube around the proximal stem whose length can be established by using the formulas for λ_a and λ_t

The analyses performed in this example show what can be done to develop an adequate stem design and to evaluate an existing stem design as regards its mechanical performance in a specific bone

Other proposals that are more qualitative can be derived from the studies presented As follows from the stress analyses the highest stresses in the cement occur close to the stem interface with peak values at the proximal and distal sides Since the strength of the cement as implanted in the bone is many times less than prefabricated (industrial) PMMA consideration could be given to the use of plastic coated stems thus placing strong material in highly stressed locations As was shown by Ypma *et al* (1979) a coated stem reduces the chances of cement fracture For the same reasons the proximal cement layer could be replaced by a (well fitting) plastic ring to resist the peak stresses here A schematic representation of these concepts is shown in fig 8 4 In this example the cement layer is only very thin over the entire fixation length giving in addition less chance of bone necrosis due to thermal damage (see section II) Since the stresses close to the cement bone interface are not so high the use of porous (acrylic) cement could be considered which would even further reduce the temperatures during the polymerization process (hence also the thermal shrinkage stresses) and would possibly ensure better interlocking with the bone thanks to bone ingrowth The stem shape in fig 8 4 has been chosen in accordance with the previously discussed example The proximal fixation region might be shortened in the course of time due to calcar resorption To prepare for this effect this region could be designed somewhat longe

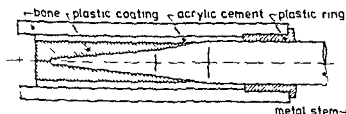


fig 8 4 A schematic concept for an idealized intramedullary fixation system using plastic coating and a plastic ring in highly stressed regions

In the examples treated here only the flexural and compressional stiffness aspects of the stem were discussed In an actual design these stiffness values have to be translated into cross-sectional geometry Since the stem on the proximal side should be as stiff as possible it should be such as to fill up the medullary canal as thoroughly as possible retaining a cement layer of at least 2 mm at the medial side On the distal side a flexible stem is needed but a large load transferring area is also advantageous Hence a cross-section that is small in the lateral medial direction and somewhat more extended in the anterior posterior direction would be possible

CHAPTER NINE

DISCUSSION

The models applied here were intended to describe the intramedullary bone prosthesis structure in a qualitative sense, to find its characteristic parameters and to evaluate the relations between these parameters and the mechanical behavior
As has been demonstrated, simplified (especially analytical) models have better options for the development of such general, fundamental concepts than detailed, geometrically refined three dimensional FEM models Of course, these refined models are in principle better suited to calculate actual stress values in an absolute sense However, bone prosthesis structures have many complicated properties which can as yet hardly be described mathematically and which do not so much affect their *mechanical behavior in general* but very much affect the local stress distribution, as was shown in chapter 6
On the other hand, however, simplified models can usually only be developed for such complicated structures when more sophisticated numerical analyses (and experiments) can serve as references In the analyses presented here, analytical models were developed on the basis that the stem and the bone separately behave by approximation in accordance with beam theory For other than intramedullary bone prosthesis structures a suitable (relatively simple) theory might not be so easily found In that case numerical analyses are all that remain However, for instance as regards the tibial plateau of the artificial knee joint, too approximative analytical theories can be applied, as was shown by Haemmerle *et al* (1977)

Owing to the qualitative character of the analyses, no comparison was made between calculated stress values and strength data of the materials and the interfaces It is difficult, too to find reliable strength criteria for cement and bone since so much depends on surgical variables and individual differences It would be realistic to assume that where the bone is concerned the stress pattern should be as natural as possible In this respect the radial transverse stresses and the shear stresses at the cement bone interface are quite unnatural for the bone and should be kept restricted as much as possible
The order of magnitude of the maximal stress values found in the cement is such, that cement failure cannot be excluded This is also true for thermal stresses caused by shrinkage immediately following the polymerization process as shown in paragraph 6 1 These stresses are maximal in the middle of the cement mass and cracks might thus develop there and not be detected during surgery Thanks to stress relaxation these locked in stresses will have no influence on the long term mechanical behavior of the structure (unless, of course, the damage was already done directly postoperatively)

Using the fundamental concepts developed here, analyses presented in the literature can be evaluated to some extent As was shown in paragraph 5 5 , the intramedullary fixation structure is not very well suited for analyses using two dimensional models If no side plates are applied in the model, a sandwich construction is in fact analysed in which unrealistically high shear stresses will occur (McNeice *et al*, 1975 1976 Andriacchi *et al*, 1975, Kwak *et al*, 1979) Furthermore slip at the stem cement (or cement bone) interface will cause the overall flexural stiffness of such a model to be reduced drastically resulting in unrealistically high stem and bone stresses
A two-dimensional FEM model using side plates was presented by Svensson *et al* (1977) They concluded from their analysis that the use of a heavier prosthesis stem may be

beneficial as we have seen this is only true for the proximal side provided a cement layer of adequate thickness is retained Their remark that stem and cement material properties do not influence the critical stress values can not be correct

The detailed three dimensional FEM models of Rohrle *et al* (1977 1979) and Scholten *et al* (1978) were mainly used for comparative studies on different prostheses designs They varied the stiffness of the stem material and reached the same conclusions as to the proximal side as were found here

A more extensive parametric analysis was carried out by Crowninshield *et al* (1979) with their three-dimensional model of an implanted hip endoprosthesis They varied the Young s moduli of the stem and the cement, the stem length and the stem thickness Generally speaking the tendencies of their results agree perfectly with the results presented here Although theirs is a profound and sophisticated study the results are rather specific owing to the empirical character of such numerical analyses They conclude that measures to be taken in order to minimize the stresses in cement or stem are in conflict As was shown here this is not true in general as can be established if the proximal and distal regions are treated sepa ately Where it is true optimal dimensions can usually be calculated They advise reducing Young s modulus of the cement (which is indeed advantageous for all stress components in the cement and will hardly affect the stem stresses) to increase the Young s modulus of the stem (only on the proximal side which follows clearly from their results too) increas ng the stem thickness (which is again only advisable for the proximal side and should not be done in general since an adequate cement layer (at least 2 mm) should be retained on the medial side) and increasing the stem length (which again should not be done in g neral as shown here the optimal length depends also on other parameters of the structure and the length should not be increased beyond this optimal value)

Since by using approximative formulas as derived here (together with such simple methods as the FEM beam model) the mechanical behavior of the structure can be adequately described in the general sense more detailed studies could be conducted by analysing more local ph nomena especially in the cement bone interface region using the approximative general results as boundary conditions and also using radiographical and histological data As discussed in paragraph 6 4 especially taking bone remodeling phenomena into account would be of interest

CHAPTER NINE

DISCUSSION

The models applied here were intended to describe the intramedullary bone prosthesis structure in a qualitative sense, to find its characteristic parameters and to evaluate the relations between these parameters and the mechanical behavior
As has been demonstrated, simplified (especially analytical) models have better options for the development of such general, fundamental concepts than detailed, geometrically refined three dimensional FEM models Of course, these refined models are in principle better suited to calculate actual stress values in an absolute sense However, bone prosthesis structures have many complicated properties which can as yet hardly be described mathematically and which do not so much affect their mechanical behavior in general but very much affect the local stress distribution, as was shown in chapter 6
On the other hand, however, simplified models can usually only be developed for such complicated structures when more sophisticated numerical analyses (and experiments) can serve as references In the analyses presented here, analytical models were developed on the basis that the stem and the bone separately behave by approximation in accordance with beam theory For other than intramedullary bone prosthesis structures a suitable (relatively simple) theory might not be so easily found In that case numerical analyses are all that remain However, for instance as regards the tibial plateau of the artificial knee joint, too approximative analytical theories can be applied, as was shown by Haemmerle *et al* (1977)

Owing to the qualitative character of the analyses, no comparison was made between calculated stress values and strength data of the materials and the interfaces It is difficult, too, to find reliable strength criteria for cement and bone since so much depends on surgical variables and individual differences It would be realistic to assume that where the bone is concerned, the stress pattern should be as natural as possible In this respect the radial transverse stresses and the shear stresses at the cement bone interface are quite unnatural for the bone and should be kept restricted as much as possible
The order of magnitude of the maximal stress values found in the cement is such, that cement failure cannot be excluded This is also true for thermal stresses caused by shrinkage immediately following the polymerization process as shown in paragraph 6 1 These stresses are maximal in the middle of the cement mass and cracks might thus develop there and not be detected during surgery Thanks to stress relaxation these locked in stresses will have no influence on the long term mechanical behavior of the structure (unless of course, the damage was already done directly postoperatively)

Using the fundamental concepts developed here analyses presented in the literature can be evaluated to some extent As was shown in paragraph 5 5 the intramedullary fixation structure is not very well suited for analyses using two dimensional models If no side plates are applied in the model, a sandwich construction is in fact analysed in which unrealistically high shear stresses will occur (McNeice *et al*, 1975 1976 Andriacchi *et al*, 1975, Kwak *et al*, 1979) Furthermore, slip at the stem cement (or cement bone) interface will cause the overall flexural stiffness of such a model to be reduced drastically resulting in unrealistically high stem and bone stresses
A two-dimensional FEM model using side plates was presented by Svensson *et al* (1977) They concluded from their analysis that the use of a heavier prosthesis stem may be

beneficial as we have seen this is only true for the proximal side provided a cement layer of adequate thickness is retained Their remark that stem and cement material properties do not influence the critical stress values can not be correct

The detailed three-dimensional FEM models of Rohrle *et al* (1977 1979) and Scholten *et al* (1978) were mainly used for comparative studies on different prostheses designs They varied the stiffness of the stem material and reached the same conclusions as to the proximal side as were found here

A more extensive parametric analysis was carried out by Crowninshield *et al* (1979) with their three-dimensional model of an implanted hip endoprosthesis They varied the Young s moduli of the stem and the cement the stem length and the stem thickness Generally speaking the tendencies of their results agree perfectly with the results presented here Although theirs is a profound and sophisticated study the results are rather specific owing to the empirical character of such numerical analyses They conclude that measures to be taken in order to minimize the stresses in cement or stem are in conflict As was shown here this is not true in general as can be established if the proximal and distal regions are treated separately Where it is true optimal dimensions can usually be calculated They advise reducing Young s modulus of the cement (which is indeed advantageous for all stress components in the cement and will hardly affect the stem stresses) to increase the Young s modulus of the stem (only on the proximal side which follows clearly from their results too) increasing the stem thickness (which is again only advisable for the proximal side and should not be done in general since an adequate cement layer (at least 2 mm) should be retained on the medial side) and increasing the stem length (which again should not be done in general as shown here the optimal length depends also on other parameters of the structure and the length should not be increased beyond this optimal value)

Since by using approximative formulas as derived here (together with such simple methods as the FEM beam model) the mechanical behavior of the structure can be adequately described in the general sense more detailed studies could be conducted by analysing more local phenomena especially in the cement bone interface region using the approximative general results as boundary conditions and also using radiographical and histological data As discussed in paragraph 6 4 especially taking bone remodeling phenomena into account would be of interest

REFERENCES

Ahmed, A M , Pak, W , Miller, J , Burke, D L and D'Souza, N (1977), Thermal stresses in polymethylmethacrylate in bone PMMA stem prosthesis fixation systems, thermo elastic solution assuming instantaneous soldifications, 3rd Annual Meeting of the Soc for Biomaterials, New Orleans, Louisiana

Andriacchi, T P Galante, J O , Belytschko, T B and Hampton, S (1975), A stresses analysis of the femoral stem in total hip prostheses, J Bone Joint Surg 58 A, No 5, p 618

Askew, M J , Lewis J L , Jaycox, Williams, J L and Hori, R Y (1978), Interface stresses in a prosthesis tibia structure with varying bone properties 24th Annual Meeting Ortho paedic Research Society, Dallas, Tex , February

Askew, M J , Lewis, J L and Kerr, L M (1979), The effect of post geometry, material and location on interface stress levels in tibial components of total knee prostheses, 25th Annual Meeting Orthopedic Research Society, San Francisco, Cal February

Banens, J (1977), Private communications, computer program FEMSYS, Computer Centre Eindhoven University of Technology, The Netherlands

Barberi, G , Gola, M , Gugliotta A and Calderale, P M (1978), Flexural coupling of h p prosthesis stem and femur a simple method of theoretical analysis, Eng in Medicine, Vol 7, No 3, p 172

Bartel, D L and Ulsoy, G A (1975), The effect of stem length and stem material on stresses in bone prosthesis systems, 21th Annual Meeting Orthopaedic Research Society San Francisco, Cal

Bartel, D L , Desormeaux S G (1976a) Femoral stem performance, Proceedings Symp Retrieval and Analysis of Orthopaedic Implants (A Weinstein, E Horowitz and A W Ruff, eds), U S Dept of Commerce, Nat Bureau of Standards Special Publication 472

Bartel, D L and Desormeaux, S G (1976b), Stresses in prosthesis stems as a function of cross sectional shape, 22nd Annual Meeting Orthopaedic Research Society, New Orleans Louisiana, January

Bartel D L and Samehyek, E (1976), The effect of cement modulus and thickness on stresses in bone prosthesis systems, 22nd Annual Meeting Orthopaedic Research Society, New Orleans Louisiana

Brekelmans, W A M , Poort H W and Slooff T J J H (1972), A new method to analyse the mechanical behaviour of skeletal parts, Acta Orthop Scand 43 pp 301 317

Brekelmans, W A M and Poort H W (1973) Theoretical and experimental investigation of the stress and strain situation on a femur Acta Orthop Bel Suppl I p 3 24

Brockhurst, P J (1975) Design of total hip prosthesis the femoral stem Centre for Bio medical Eng Report, Univ of New South Wales Australia

Calderale, P M Gola, M M and Gugliotta, A (1977) Calculation of load distribution between bone and prosthesis stem by an analytical method, comparison of several stem types, 6th Int Conf of Biomechanics, Copenhagen published (abstract) in (1978) "Biomechanics VI B, Int Series on Biomechanics (E Asmussen and K Jørgensen eds) University Park Press, Baltimore MD

Campen v D H (1970), On the stress distribution in an arbitrarily loaded nozzle to flat plate connection, Nucl Eng Des 11 pp 495 516

Campen, v D H Croon, H W and Lindwer J (1978) Influence of cyclic loading on mechanical loosening of hinged knee prostheses Eng in Med Vol 7 no 4 p 235

Campen, v D H , Croon H W and Lindwer J (1979) Mechanical loosening of knee endoprostheses with intermedullary stems, Influence of dynamic loading, 25th Annual Meeting Orthopaedic Research Soc San Francisco Cal , February

Chand R Huang E and Rim K (1976) Stresses in the human knee joint, J Biomechanics vol 9 pp 417 422
Chao E Y, Wong H W Frain W E and Coventry M B (1977), Stress analysis of the geometric knee under static loading ASME 77 Bio-6
Crowninshield R D and Branch A J (1978) The effect of stem cross-sectional shape on the load transmission from total hip prostheses 24th Annual Meeting Orthopaedic Research Society Dallas Tex February
Crowninshield R D Brand R A and Johnston R C (1979) An analysis of femoral stem design in total hip arthroplasty 25th Annual Meeting Orthopaedic Research Society San Francisco Cal, February
Durelli, A J (1977) The difficult choice Evaluation of methods used to determine experimentally displacements, strains and stresses Appl Mech Rev vol 30 no 9 p 1167
Evans F G (1973) Mechanical properties of bone Charles C Thomas Publ, Springfield Ill
Forte M R (1975) Structural analysis consideration in the design of the total hip prosthesis 21th Annual Meeting Orthopaedic Research Society San Francisco Cal Febr March
Girkmann K (1963) Flachentragwerke (6th ed) Springer Verlag Wien New York
Gola M M and Gugliotta A A (1979) Analytical estimate of stresses in bone and prosthesis stems J Strain Anal vol 14 no 1 p 29
Gruen T A and Amstutz H C (1977) Modes of failure of the cement stem type femoral component 30th ACEMB Los Angelos Cal p 87 proceedings
Haemmerle J Bartel D and Chao E Y (1977) Mechanical analysis of polycentric tibial track loosening ASME publication 77 Bio 7
Hampton S J Andriacchi T P Galante J O and Belytschko T B (1976) Analytical approach to the study of stresses in the femoral stem of total hip prostheses paper 32 1 29th ACEMB Boston Mass November
Harris L J Chao R, Bloch R and Weingarten V (1978) A three-dimensional Finite Element Analysi of the proximal third of the femur 24th Annual Meeting Orthopaedic Research Society Dallas Tex February
Hayes W C Swenson L W and Schurman D J (1978) Axisymmetric finite element analysis of the lateral tibial plateau J Biomechanics Vol 11 p 21 33
Hayes W C (1978) Theoretical modeling and design of implant systems Workshop Mechanical failure of total joint replacement Atlanta Georgia May 31 June 2 The Steering Committee Am Ac of Orthop Surg Chicago Document 916 78
Heck v J and Huiskes R (1979) Berekeningen op basis van de elementenmethode en een Fourier analyse aan een nieuwe gewrichtsprothese uit de Orthopaedie De Wagner prothese Lab for Exp Orthop Dept Orthopaedics (ORa 79 08) Univ of Nijmegen The Netherlands
Hetenyi M (1946) Beams on elastic foundation The Univ of Michigan Press Ann Arbor Mich
Heugten v P C M (1974) Rekstrookmetingen verricht aan een kadaverfemur in ongeschonden toestand en voorzien van diverse prothesen Report Dept Applied Mechanics (W WE 74-18) Eindhoven Univ of Technology The Netherlands
Heugten v P C M (1975) Spanningsanalyse van de schacht van het femur op basis van een balkmodel Report Dept Applied Mechanics (W WE 75 06) Eindhoven Univ of Technology The Netherlands
Huggler A H Jacob H A C und Schreiber A (1978) Biomechanische Analyse der Lockerung von Femurprothesen Arch Orthop Traumat Surg 92 p 261 272
Huiskes R and van Heugten P C M (1974) A discussion of problem solving methods in biomechanical research Combined meeting of the Dutch and Danish Orthopaedic Associations Nijmegen The Netherlands published in proceedings (Biermans et al, eds)

Huiskes, R v Heugten, P C M and Slooff, T J J H (1976), Strain gauge measurements on a loaded femur, intact as well as provided with prostheses, 29th ACEMB, Boston Mass, November

Huiskes, R (1977), Kriteria voor ontwerp en fixatie van orthopaedische implantaten op basis van FEM berekeningen, Report Lab for Exp Orthopaedics, Dept Orthopaedics (RH 77 10), University of Nijmegen, The Netherlands

Huiskes R, Elangovan, P T, Banens, J P A and Slooff, T J J H (1977), Finite element computer methods for design and fixation problems of orthopaedic implants, In 'Bio mechanics VI B, Int Series on Biomechanics" (E Asmussen and K Jørgensen, eds), Univ Park Press, Baltimore, M D

Huiskes, R et Slooff, T J J H (1977), Etude des contraintes a la fixation des articulations artificielles, 2ième Congres de la Soc de la Biomechanique, Liege, Belgium, sept 21 23

Huiskes, R (1978), Stress analyses of implanted orthopaedic joint prostheses for optimal design and fixation First Conf Europ Soc of Biomechanics, Brussels Belgium, May

Huiskes, R and Heck, v J (1978), Stress analysis and optimization of a new intramedullary fixation system, to be used in finger joint prostheses, Report Lab for Exp Orthopaedics Dept Orthopaedics (ORa 78 04) Univ of Nijmegen The Netherlands

Huiskes, R and Slooff, T J J H (1978), Mechanical properties and stresses in intramedullary prostheses, 24th Annual Meeting Orthopaedic Research Society, Dallas, Tex, February

Huiskes, R (1979), Principal parameters in the mechanical performance of intramedullary fixated artificial joints, 2nd Meeting Eur Soc of Biomechanics, Strasbourg, France September

Huiskes, R, v Heck, J, Walker P S and Green, D J (1979), A three dimensional stress analysis of a new intramedullary fixation system, 25th Annual Meeting Orthopaedic Research Society, San Francisco, Cal, February

Huiskes, R and Schouten, R Y (1979), Stiffness characteristics and stress distribution of a slice of bone cement, surrounding an intramedullary fixated orthopaedic implant, Report Lab for Exp Orthopaedics, Dept Orthopaedics (ORa 79 03) Univ of Nijmegen, The Netherlands

Huiskes, R und Slooff T J J H (1979a) Experimentelle und rechnerische Spannungs analysen der Huftgelenk Verankerung, Pauwels Symposium, Berlin, Jan

Huiskes, R and Slooff T J J H (1979b), Geometrical and Mechanical properties of the human femur, 7th Int Conf of Biomechanics, Warsaw Poland september, To be published in Biomechanics VII, Int Series on Biomechanics (K Fidelius and A Morecki, eds), Univ Park Press, Baltimore M D

Huiskes, R and Wijn, de J R (1979), Locked in acrylic cement stresses, caused by thermal shrinkage after fixation of intramedullary joint prostheses, 2nd Meeting Eur Soc of Biomechanics Strasbourg France September

Kempf I, Jaeger J H, Nessius A Mochel D et Clavert J M (1976), Etude comperative de l élément fémoral de quelques arthroplasties totales de la hanche Acta Orthop Belg Tome 42, Suppl I

Koch, J C (1917), The laws of Bone Architecture Am J Anat vol 21

Kwak, B M Lim, O K, Kim Y Y and Rim, K (1979) An investigation of the effect of cement thickness on an implant by finite element stress analysis Int Orthop (SICOT) 2 pp 315 319

Laaper, W (1973a), Het bepalen van de geometrie van het femur op destructieve wijze Report Dept Applied Mechanics (W WE 73 5) Eindhoven Univ of Technology The Netherlands

Laaper, W (1973b), Spanningsanalyse van het femur op basis van een balkmodel, Report Dept Applied Mechanics (W WE 73 12) Eindhoven Univ of Technology The Netherlands

Lewis J L (1977) Analytical methods in prosthesis design Proc Workshop on Internal Joint Replacement Northwestern Univ Chicago pp 127 134

McBeath A A Schopler S A and Seireg A A (1979) *Circumferential and longitudinal* strain in the proximal femur as determined by prosthesis (THR) type and position 25th Annual Meeting Orthop Res Soc San Francisco Cal February

McNeice G M Eng P and Amstutz H C (1975) Finite element studies in hip reconstruction 5th Int Conf of Biomechanics Jyvaskyla Finland Published in (1976) Biomechanics VA Int Series on Biomechanics (P V Komi ed) Univ Park Press Baltimore M D

McNeice G M and Amstutz H C (1976) Stresses in prostheses stems and supporting acrylic a finite element study of hip replacement 22nd Annual Meeting Orthopaedic Research Society New Orleans Louisiana January

McNeice G M and Gruen T A (1976) Mechanical failure of femoral components radio graphic examination of total hip replacement 22nd Annual Meeting Orthopaedic Research Society New Orleans Louisiana January

Meyer H (1867) Die Architectur der Spongiosa Archiv f Anat Phys und Wissensch Medizin p 615

Minns R J Bremble G R and Campbell J (1977) A biomechanical study of internal fixation of the tibial shaft J Biomech vol 10 pp 569 579

Morscher E Mathys R and Hence H R (1976) Iso elastic endoprosthesis – a new con ept in artificial joint replacement In Advances in artificial hip and knee joint technology (Schaldach and Hohmann eds) Springer Verlag Berlin Heidelberg New York

Muskhelishvili N I (1963) Some basic problems of the mathematical theory of elasticity P Noordhoff Groningen The Netherlands

Oden J T and Bathe K J (1978) A commentary on computational mechanics Appl Mech Rev vol 31 no 8 p 1053

Oh I and Harris W H (1978) Proximal strain distribution in the loaded femur J Bone Joint Surg 60-A No 1 p 75

Olofsson H (1975) The stress distribution in the femur IRCOBI Conf Birmingham

Olofsson H (1976) Three-dimensional FEM calculation of elastic stress field in human femur Thesis Technikum Inst of Technology Uppsala Univ Uppsala Sweden

Piziali R L Hight T K and Nagel D A (1976) An extended structural analysis of long bones – Application to the human tibia J Biomech 9 no 11 p 695

Rohlmann A Bergmann G und Kolbel R (1978) Aussagewert und Grenzen der Spannungsberechnung mit der Finiten Element Methode (FEM) bei orthopadischen Probleme Submitted for publication Z *Orthop Chir u i Grenzgebiete*

Rohlmann A Kölbel R and Bergmann G (1977) *Practical* value of the finite-element method for the stress calculation at the implant bone surface 6th Int Conf of Bio mechanics Copenhagen published (abstract) in (1978) *Biomech VI B* Int Series on Biomechanics (E Asmussen and K Jørgensen eds) Univ Park Press Baltimore M D

Rohlmann A Kölbel R und Bergmann G (1979) Über den Aussagewert der Finiten Element Methode bei orthopadische Problemen Pauwels-Symposium Berlin January 19 20 to be published

Rohrle H Scholten R Solbach W Ritter G und Grunert A (1977) Der Kraftflusz bei Huftendoprothesen Arch Orthop Unfall-Chir 89 49 60

Rohrle H Scholten R und Sollbach W (1979) Der Kraftflusz bei neuartigen Huftendoprothesen Pauwels-Symposium Berlin Febr 18 19 to be published

Rybicki E F Simonen F A and Weis E B Jr (1972) On the mathematical analysis of stress in the human femur J Biomechanics vol 5 p 203 215

Huiskes, R v Heugten, P C M and Slooff T J J H (1976), *Strain gauge measurements on a loaded femur, intact as well as provided with prostheses*, 29th ACEMB, Boston Mass, *November*

Huiskes, R (1977), Kriteria voor ontwerp en fixatie van orthopaedische implantaten op basis van FEM berekeningen, Report Lab for Exp Orthopaedics, Dept Orthopaedics (RH 77 10), University of Nijmegen The Netherlands

Huiskes, R, Elangovan, P T, Banens, J P A and Slooff, T J J H (1977), Finite element computer methods for design and fixation problems of orthopaedic implants, In "Biomechanics VI B Int Series on Biomechanics" (E Asmussen and K Jørgensen, eds), Univ Park Press, Baltimore, M D

Huiskes R et Slooff, T J J H (1977), Etude des contraintes a la fixation des articulations artificielles, 2ieme Congres de la Soc de la Biomechanique, Liege, Belgium, sept 21 23

Huiskes R (1978), Stress analyses of implanted orthopaedic joint prostheses for optimal *design and fixation, First Conf Europ Soc of Biomechanics, Brussels, Belgium, May*

Huiskes, R and Heck, v J (1978), Stress analysis and optimization of a new intramedullary fixation system, to be used in finger joint prostheses, Report Lab for Exp Orthopaedics, *Dept Orthopaedics (ORa 78 04)* Univ of Nijmegen, *The Netherlands*

Huiskes R and Slooff, T J J H (1978), Mechanical properties and stresses in intramedullary prostheses 24th Annual Meeting Orthopaedic Research Society, Dallas, Tex, February

Huiskes, R (1979), *Principal parameters in the mechanical performance of intramedullary fixated artificial joints, 2nd Meeting Eur Soc* of Biomechanics, Strasbourg, France September

Huiskes, R, v Heck J, Walker P S and Green, D J (1979), A three dimensional stress analysis of a new intramedullary fixation system, 25th Annual Meeting Orthopaedic *Research Society, San Francisco, Cal, February*

Huiskes, R and Schouten R Y (1979), *Stiffness characteristics and stress distribution of a slice of bone cement, surrounding an intramedullary fixated orthopaedic implant*, Report Lab for Exp Orthopaedics, Dept Orthopaedics *(ORa 79 03) Univ of Nijmegen, The* Netherlands

Huiskes, R und Slooff T J J H (1979a), Experimentelle und rechnerische Spannungs*analysen der Huftgelenk Verankerung, Pauwels Symposium, Berlin, Jan*

Huiskes, R and Slooff T J J H (1979b), Geometrical and Mechanical properties of the human femur, 7th Int Conf of Biomechanics, Warsaw Poland, september, To be published in *Biomechanics VII, Int Series on Biomechanics (K Fidelius and A* Morecki eds), Univ Park Press Baltimore M D

Huiskes R and Wijn de J R (1979), Locked in acrylic cement stresses, caused by thermal shrinkage after fixation of intramedullary joint prostheses *2nd Meeting Eur Soc of* Biomechanics Strasbourg, France, September

Kempf I Jaeger, J H, Nessius, A, Mochel D et Clavert, J M (1976), Etude comperative *de l'element fémoral de quelques arthroplasties totales de la hanche*, Acta Orthop Belg Tome 42 Suppl I

Koch, J C (1917) The laws of *Bone Architecture Am J* Anat vol 21

Kwak B M, Lim, O K Kim, Y Y and Rim, K *(1979) An investigation of the effect of cement thickness on an implant by finite element stress analysis*, Int Orthop (SICOT) 2 pp 315 319

Laaper, W (1973a) Het bepalen van *de geometrie van het femur op destructieve wijze* Report Dept Applied Mechanics (W WE 73 5) *Eindhoven Univ of Technology The* Netherlands

Laaper W (1973b) Spanningsanalyse van het femur op *basis van een balkmodel Report* Dept Applied Mechanics (W WE 73 12) Eindhoven *Univ of Technology The Netherlands*

APPENDICES

Scholten, R (1975), Über die Berechnung der mechanische Beanspruchung in Knochen strukturen mittels fur den Flugzeugbau entwickelte Rechenverfahren, Med Orthop *Technik, Heft 6/75, 95 Jahrgang* s 130 138

Scholten, R, Rohrle, H und Sollbach, W (1978), Analysis of stress distribution in natural and artificial hip joints using the finite element method, *The South Afr Mech Eng* vol 28, p 220

Schoofs, B (1979), private communication

Slooff, T J J H (1970), De invloed van het acrylcement bij de fixatie van de heupendoprothese, Dissertation, Univ of Nijmegen, The Netherlands

Slooff T J J H (1971), *Spannungsveranderungen im proximalen Femurende bei einzemen* tierten Endoprothesen, Arch Orthop Unfall Chir 71 s 281 289

Stern, J (1977), Zur Beanspruchung des Knochenzementes bei der Huftgelenkendoprothese, Arch Orthop Unfall Chir *88*, pp 309 312

Svensson, N L, Valliapan, S and Wood R D (1977), Stress analysis of human femur with implanted Charnley prosthesis, *J Biomechanics, vol 10* pp *581 588*

Swanson S A V and Freeman M A R (1977), The scientific basis of joint replacement Pitman Med Publ Comp, Tunbridge Wells

Timoshenko, S P and Goodier, J N (1970), Theory of elasticity, (3rd ed), McGraw Hill Kogahuska, Tokyo

Toridis Th G (1969), Stress analysis of the femur, *J Biomechanics* vol 2 *pp 163 174*

Tarr, R R, Lewis J L Jaycox D Sarmiento A Schmidt J and Latta, L L (1979), Effect of materials stem geometry and collar calcar contact on stress distribution in the proximal femur with total hip, 25th Annual Meeting Orthopaedic Research Society, San Francisco, Cal February

Valliapan, S, Svensson N L and Wood R D (1977), Three dimensional stress analysis of the human femur, Comput *Biol Med* vol *7*, pp 253 264

Vichnin H H and Batterman, *S C (1977) Three dimensional anisotropic stress analysis* and failure prediction in a femur with a proximal prosthesis 30th ACEMB, Los Angelos Cal, November

Walker, P S (1977), Human joints and their artificial replacement, Charles C Thomas Publ Springfield, Ill

Wilson, E L *(1965) Structural analysis of axisymmetric solids A I A A no 3 pp 2269* 2274

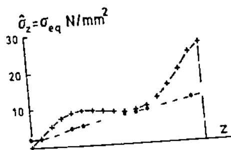
Wolff, J (1870), Über die Innere Architectur der Knochen und ihre Bedeutung fur die Frage vom Knochenwachtstum Virchow s Arch f path Anat u Phys 50 s 389

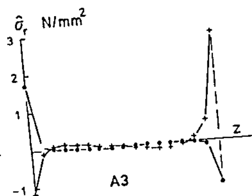
Wood R Valliapan S and Svensson N L (1973) Stress analysis of human femur, In Theory and practice *in FEM structural analysis Tokyo Seminar* (Y Yamada and R H Gallagher eds) *Univ* of Tokyo Press, Tokyo

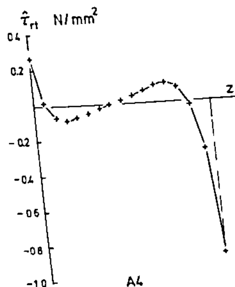
Wood, R D (1975), Stress analysis of the femur, Thesis *Univ* of New South Wales Australia

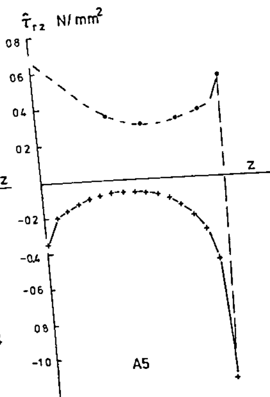
Ypma, J, de Wijn, J, Huiskes, R and Slooff, T *(1979)*, Strength and ingrowth aspects of porous acrylic bone cement, 11th *Int Biomaterials Symp, Clemson Univ So Car* April May

Zienkiewicz, O C (1977), The finite element method McGraw Hill London 3rd ed


$\hat{\sigma}_z = \sigma_{eq}$ N/mm²
30
20
10
z
A2


$\hat{\sigma}_r$ N/mm²
3
2
1
−1
z
A3


$\hat{\tau}_{rt}$ N/mm²
0.4
0.2
−0.2
−0.4
−0.6
−0.8
−1.0
z
A4


$\hat{\tau}_{rz}$ N/mm²
0.8
0.6
0.4
0.2
−0.2
−0.4
−0.6
0.8
−1.0
z
A5

APPENDIX A

RESULTS OF THE THREE DIMENSIONAL FEM CALCULATIONS

The following graphs show the values of the stress 'amplitudes', σ_r, σ_t, σ_z, τ_{rt}, τ_{rz} τ_{tz} and the equivalent stress σ_{eq} (maximal value) as functions of z, for $r = r_s$ and $r = r_b$ (lines 1 and 2 3 and 4 respectively), calculated with the three dimensional FEM model for two loading cases (fig A 1) For the stem only σ_z has been drawn, since the other stress components have insignificant values in comparison It should be borne in mind that τ_{rt} and τ_{tz} are zero for the axial loading case and therefore have not been drawn also

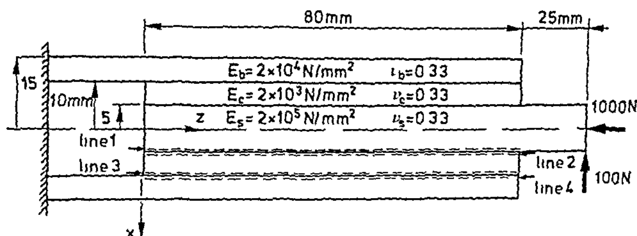


fig A 1 Characterization of the structure for which the stress amplitudes are given in the following graphs

Three stress components are continuous across the interface (σ_r τ_{rt} and τ_{rz}) thus equal in both materials These components are referred to as interface stresses and the values shown are those for the cement (in the calculations the continuity is not always exactly fulfilled Huiskes, 1977)

The following line codes are used

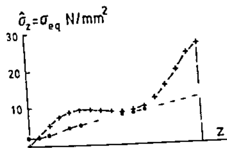
Axial Force (Z)

+ + + *Transverse Force (X)*

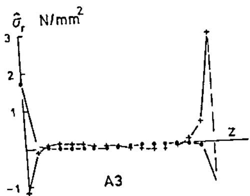
The dots refer to the nodal point values

Results for the loading case M have not been drawn since they in a general sense give the same kind of information as those for loading case X

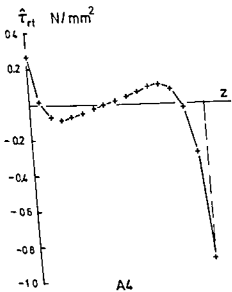
Fig A 2 stem stresses line 1 ($r = r_s$) figs A 3 through A 5 stem cement interface stresses line 2 ($r = r_s$) figs A 6 through A 9 *cement stresses, line 2 ($r = r_s$), figs* A 10 through A 13 cement stresses, line 3 ($r = r_b$) figs A 14 through A 16 cement bone interface stresses line 3 ($r = r_b$), figs A 17 through A 20 *bone stresses line 4 ($r = r_b$)*



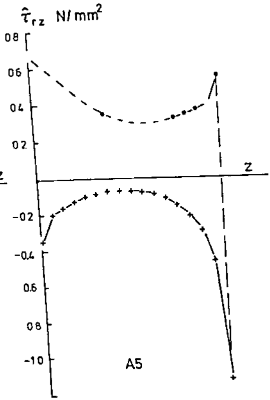
$\hat{\sigma}_z = \sigma_{eq}$ N/mm^2
30
20
10
z
A2



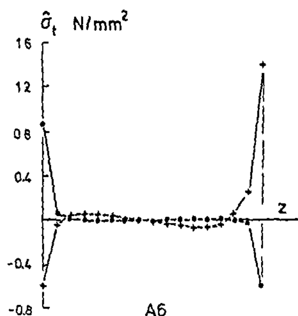
$\hat{\sigma}_r$ N/mm^2
3
2
1
−1
z
A3



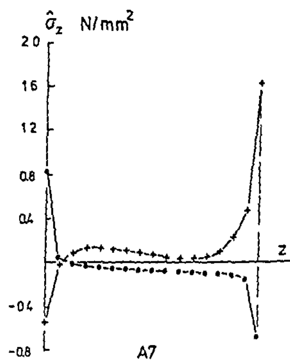
$\hat{\tau}_{rt}$ N/mm^2
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
z
A4



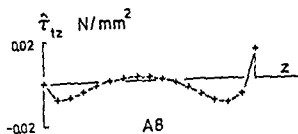
$\hat{\tau}_{rz}$ N/mm^2
0.8
0.6
0.4
0.2
-0.2
-0.4
0.6
0.8
-1.0
z
A5



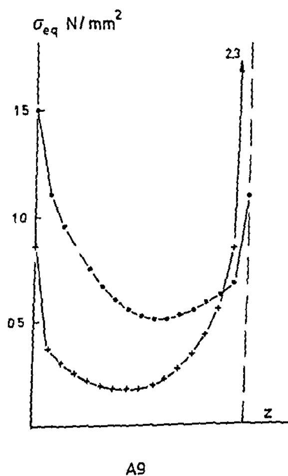
$\hat{\sigma}_t$ N/mm²
16
12
0.8
0.4
-0.4
-0.8
z
A6



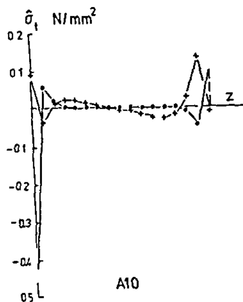
$\hat{\sigma}_z$ N/mm²
2.0
16
12
0.8
0.4
-0.4
-0.8
z
A7

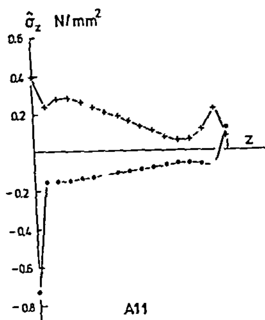


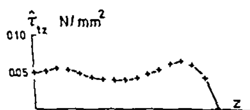
$\hat{\tau}_{tz}$ N/mm²
0.02
-0.02
z
A8

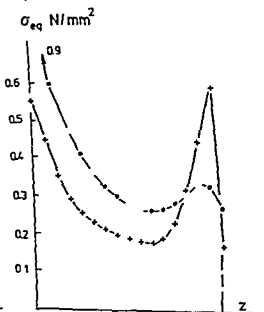


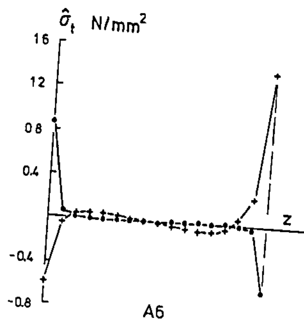
σ_{eq} N/mm²
2.3
15
10
0.5
z
A9

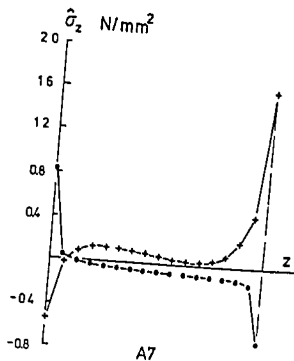

$\hat{\sigma}_t$ N/mm^2
0.2
0.1
z
-0.1
-0.2
-0.3
-0.4
0.5
A10

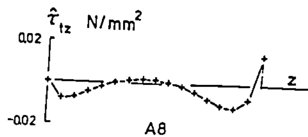

$\hat{\sigma}_z$ N/mm^2
0.6
0.4
0.2
z
-0.2
-0.4
-0.6
-0.8
A11

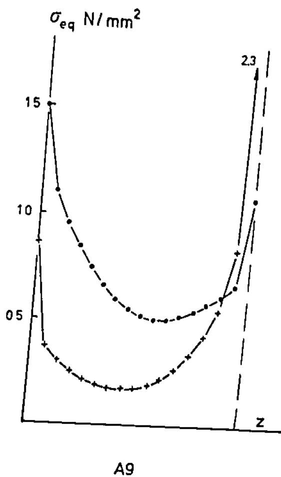

$\hat{\tau}_{tz}$ N/mm^2
0.10
0.05
z
A12

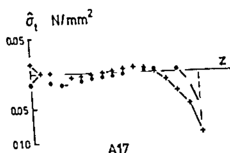

σ_{eq} N/mm^2
0.9
0.6
0.5
0.4
0.3
0.2
0.1
z
A13


$\hat{\sigma}_t$ N/mm²
1.6
1.2
0.8
0.4
-0.4
-0.8
z
A6

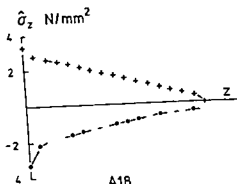

$\hat{\sigma}_z$ N/mm²
2.0
1.6
1.2
0.8
0.4
-0.4
-0.8
z
A7


$\hat{\tau}_{tz}$ N/mm²
0.02
-0.02
z
A8

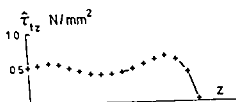

σ_{eq} N/mm²
2.3
1.5
1.0
0.5
z
A9



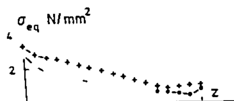
A17



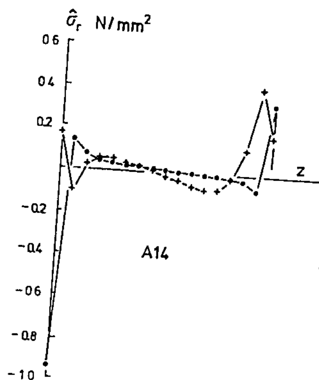
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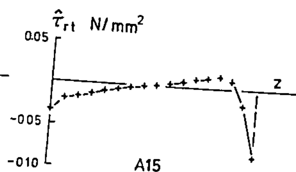


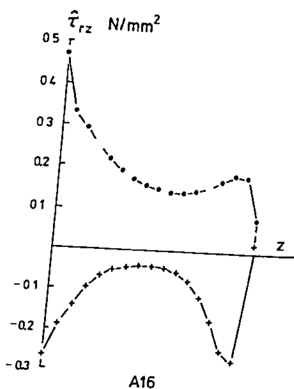
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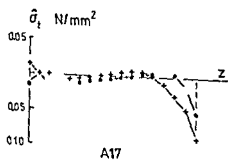


A20

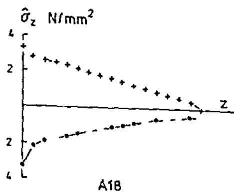

$\hat{\sigma}_r$ N/mm²
0.6
0.4
0.2
z
-0.2
-0.4
-0.6
-0.8
-1.0
A14


$\hat{\tau}_{rt}$ N/mm²
0.05
z
-0.05
-0.10
A15

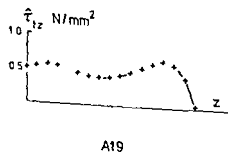

$\hat{\tau}_{rz}$ N/mm²
0.5
0.4
0.3
0.2
0.1
z
-0.1
-0.2
-0.3
A16



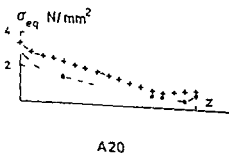
A17



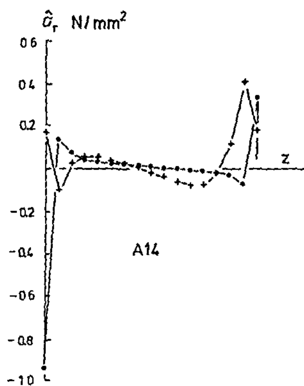
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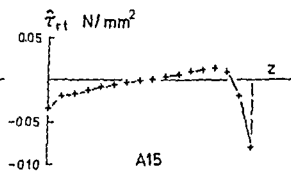


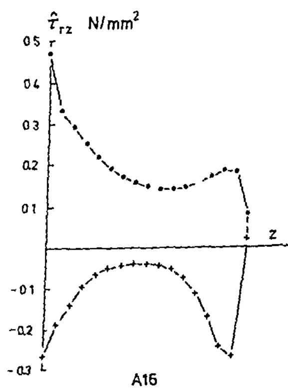
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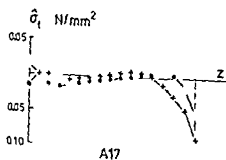


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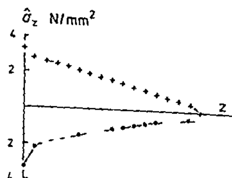

$\hat{\sigma}_r$ N/mm^2
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
z
A14


$\hat{\tau}_{rt}$ N/mm^2
0.05
-0.05
-0.10
z
A15

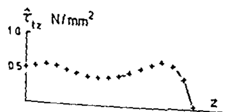

$\hat{\tau}_{rz}$ N/mm^2
0.5
0.4
0.3
0.2
0.1
-0.1
-0.2
-0.3
z
A16



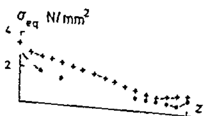
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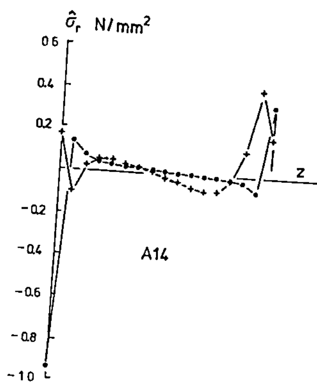
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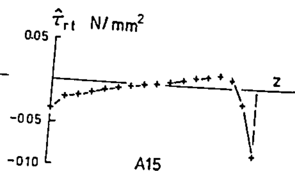
A19



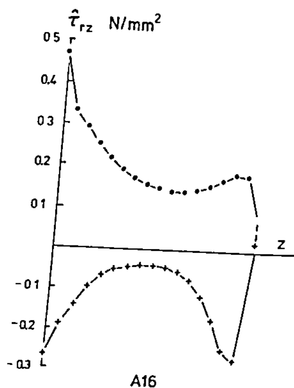
A20



$\hat{\sigma}_r$ N/mm²
0.6
0.4
0.2
-0.2
-0.4
-0.6
-0.8
-1.0
z
A14



$\hat{\tau}_{rt}$ N/mm²
0.05
-0.05
-0.10
z
A15



$\hat{\tau}_{rz}$ N/mm²
0.5
0.4
0.3
0.2
0.1
-0.1
-0.2
-0.3
z
A16

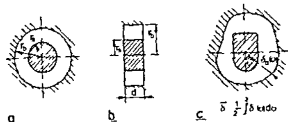


fig B 2 Different cross sectional geometries of a cement slice (a) axisymmetric (b) rectangular and (c) arbitrary

where γ_s is the circumference of the stem $\bar{\delta}_a$ the average layer thickness
For $\rho = 0\ 5$ ($r_b - r_s = 5$ mm) formulas (B 1) and (B 2) gave good agreements with FEM calculations For higher ρ the accuracy will be even better for smaller ρ the accuracy will decrease
Formula (B 3) is an extrapolation of (B 1) and (B 2) and should only be expected to give reasonable results if the layer is thin and the variation in thickness restricted When formula (B 3) is used to approximate C_a for circular geometry for $\rho = 0\ 5$ an under estimation of about 30% results compared to (B 1) for $\rho = 0\ 7$ agreement is quite reasonable

Stiffness against transverse loading

A slice dz of the structure is shown in fig B 3 The bone and the stem are assumed to be rigid Plane strain state is assumed in the cement layer (for plane stress state see Huiskes and Schouten 1979) The results for different cases are summarized in table B 1

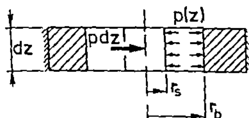


fig B 3 A slice of the structure in transverse loading

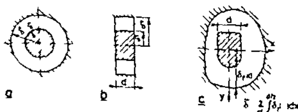


fig B 4 Different cross sectional geometries of a cement slice (a) axisymmetric (b) rectangular and (c) arbitrary

APPENDIX B

THE STRUCTURAL STIFFNESS OF A SLICE OF BONE CEMENT

In the beams on elastic foundation models the Winkler hypothesis is applied to the acrylic cement layer, which means that the layer is assumed to consist of an infinite number of linear elastic springs, with spring constants C_a (N/mm^2) for axial loading and C_t (N/mm^2) for transverse loading Approximative formulas for C_a and C_t can be derived using analytical and FEM models These analyses have been described in Huiskes and Schouten (1979), in this appendix only a summary of the results is given

Stiffness against axial shear

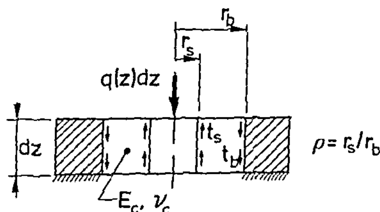


fig B 1 A slice of the structure n axial loading

A slice dz of the structure is shown in fig B 1 The bone and the stem are assumed as rigid The Winkler hypothesis in this case implies that only shear stress in the axial direction is present in the cement layer For circular geometry it follows (fig B 2 a) that

$$C_a \approx - \frac{\pi E_c}{(1+\nu_c)\ln\rho} \quad (\rho = r_s/r_b) \tag{B 1}$$

for rectangular geometry (plane model) (fig B 2 b) we have

$$C_a \approx \frac{d E_c}{(r_b - r_s)(1+\nu_c)} \tag{B 2}$$

and for arbitrary geometry (fig B 2 c)

$$C_a \approx \frac{1}{2} \frac{\gamma_s E_c}{\delta_a (1+\nu_c)} \tag{B 3}$$

(B 8) and (B 9) and will presumably give reasonable results if the stem geometry is not too irregular If formula (B 10) is used to approximate C_t in circular geometry the agreement with the FEM results is even better than when formula (B 4) is used, formula (B 10) is however somewhat inconvenient since for circular geometry

$$\delta_t = \frac{1}{2} r_b \left\{ \sqrt{(1-\rho^2)} + \frac{1}{\rho} \arcsin\rho - \frac{\pi}{2}\rho \right\}$$

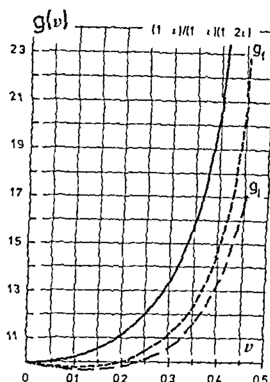


fig B 5 Three functions of ν_c, used in the expressions for C_t

	stem cement interface rigidly connected		stem cement interface loose and no friction	
circular geometry (1) (fig B 4 a)	$5\,3E_c g_f(\nu_c)\,(0\,24 + \frac{\rho}{1-\rho})$	(B 4)	$1\,9E_c g_l(\nu_c)\,(0\,24 + \frac{\rho}{1-\rho})$	(B 5)
rough approximation	$\frac{4E_c(1-\nu_c)\rho}{(1-\rho)(1+\nu_c)(1-2\nu_c)}$	(B 6)	$\frac{2E_c(1-\nu_c)\rho}{(1-\rho)(1+\nu_c)(1-2\nu_c)}$	(B 7)
rectangular geometry (fig B 4 b) uni axial strain assumed	$\frac{2dE_c(1-\nu_c)}{(r_b-r_s)(1+\nu_c)(1-2\nu_c)}$	(B 8)	$\frac{dE_c(1-\nu_c)}{(r_b-r_s)(1+\nu_c)(1-2\nu_c)}$	(B 9)
arbitrary cross section (fig B 4 c)	$\frac{2\,5dE_c(1-\nu_c)}{\delta_t(1+\nu_c)(1-2\nu_c)}$	(B 10)	$\frac{1\,25dE_c(1-\nu_c)}{\delta_t(1+\nu_c)(1-2\nu_c)}$	(B 11)

table B 1 Approximative formulas for C_t in different circumstances (1) for g_f and g_l see fig B 5

Formulas (B 8) and (B 9) were derived analytically and apply exactly for the assumption of uniaxial strain Formulas (B 4) (B 5) (B 6) and (B 7) were derived from analytical considera tions combined with FEM calculations Formulas (B 10) and (B 11) were extrapolated from

SECTION FOUR

CONCLUSIONS AND CLOSING REMARKS

In view of the probable ranges in the parameter values on the one hand and the ranges in thermal necrosis threshold levels on the other it can be concluded from the analyses that thermal necrosis in the cortex of the bone during fixation of intramedullary stems is improbable that the incidence of thermal necrosis in general cannot be excluded and that in specific (predictable) circumstances it will certainly occur

The heat conduction process and the temperature values are significantly influenced by the dimensions of the bone Hence when heat conduction phenomena or their consequences as regards thermal necrosis (for instance in histological analyses) are studied in smaller animal models the results cannot simply be translated to human circumstances In this respect it is found to be rather unlikely that the cortical bone necrosis reported by Feith (1975 see section II) in his rabbit experiments was mainly caused by thermal necrosis By combining his experimental results with those of the analyses presented here the hypothesis evolves that the heat of polymerizing has an indirect effect by influencing the cell toxic actions of the monomer rather than a direct necrotic effect on the bone tissue

In order to reduce the temperatures several precautions can be taken Adding heat sinks as radiopaque fillers ($BaSO_4$ or ZrO_2) to the powder has but little effect Pre cooling of the implant and the cement for instance by 10 C is also of little effect while more drastic cooling will probably prejudice the polymerization process More influence is exerted by the addition of an aqueous gel to the cement mixture (porous cement) and by increasing the powder to-liquid ratio although these measures can only be applied in a limited sense since in this case too the cement properties especially its strength may suffer Decreasing the polymerization rate has a moderate influence but when the auto-acceleration effect is drastically surpressed the maximal temperatures will be significantly reduced A quite effective and useful measure is the cooling of the operation region before cement insertion and during the polymerization process The effectiveness of these measures can easily be evaluated by using the graphs presented in chapter 9 of section II
The surgeon furthermore can effectively reduce the temperatures by limiting the amounts of cement used In this respect it should be noted that acrylic cement in fact fulfills *two* different functions adapting the smooth implant to the irregular implant bed and filling spaces The latter function could be provided by pre polymerized materials as well by applying plastic fillers of different dimensions and shape and plastic coated implants In that case only little self curing acrylic cement would have to be used thus reducing the bone temperatures and the chances of thermal tissue damage

Stress analyses

By applying beams-on-elastic foundation theory to a simplified general model of intra medullary fixation structures (using results of *experimental* and three d ional Finite Element Method analyses as references) *the cha ac eristic* mechanical parameters of the structure can be determined and the relations between these parameters and its mechanical performance evaluated It can be shown that the *structure* can be divided into a *proximal* a distal and a middle region which can be analysed separately Simple approximative formulas can be derived for the most important stress values in these regions (in the stem the bone the intermediate layer (usually acrylic cement) and at the interfaces)

By applying fundamental general concepts thus obtained it can be shown that *two-dimensional* (plane) Finite Element *Methods* as reported in the *literature* are not very suitable for

The analyses, discussed in the previous sections, provide fundamental data from which guidelines for prosthesis designs, implantation procedures and acrylic cement composition can be derived Obviously, the aspects treated here are not the only ones that provide guidelines others, too affect the system performance and the designs and procedures ultimately chosen will usually be based on compromises between criteria of biological, mechanical, chemical and surgical origin In this respect the recommendations resulting from the analyses presented here are partial in character and should therefore certainly not be regarded as prescriptions but merely as guidelines It is evident, however, that any compromise will have more chances of succes when its various (possibly conflicting) criteria are in themselves firmly based on fundamental data

Conclusions have been stated at different stages in sections II and III, in the following pages some of them, that may be of interest to orthopedic surgeons, will be discussed in more general terms

Heat generation and conduction analyses

The heat generation and conduction process in polymerizing acrylic cement and the materials adjacent to it can be described mathematically with quite reasonable accuracy by applying theories of heat conduction In this way the temperatures as a function of time in a given bone prosthesis structure during and after polymerization can be predicted by approximation The parameters that describe the thermal properties of the relevant materials that have to be used in the calculations can be estimated on the basis of literature data In some cases especially as regards the bone tissue only a range of probable values can be found

The cement bone interface is a region rather than a smooth well defined area of contact, which has a certain heat flow resistance Consequently a steep temperature drop will occur over a relatively small distance and hence the cement bone interface temperature is an undefined quantity, a fact to which the scatter in experimental data as reported in the literature can at least partly, be ascribed The thermal conductivity of the interface greatly influences the maximal bone temperature values and the penetration depth of the heat into the bone Anything that can be done to reduce the interface conductivity also reduces the chances of bone necrosis and from this point of view cleansing of the implant bed prior to cement insertion would not be advantageous (contrarily, however, to criteria of mechanical interface strength)

During acetabular cup fixation the temperatures occurring in the bone adjacent to the cement are higher than those in the case of intramedullary (metal) stem fixation The maximal values greatly depend on the amounts of cement used and on the (macro) geometry of the bony implant bed which should be smooth and concave When acrylic cement is pressed against trabecular bone the tips of trabeculae surrounded by cement may reach temperatures up to 70°C at which instant thermal necrosis is a certainty in view of the literature data on thermal necrosis threshold levels

Apart from these trabecular tips the bone adjacent to the cement may in general reach maximal temperatures of roughly speaking 50 to 60°C while a bone layer of 1 to 4 mm may be heated to 50°C or beyond depending on the specific circumstances In this range, the occurrence of thermal necrosis greatly depends on the time of exposure For an exposure time of 30 sec thermal threshold levels for cell necrosis between 50 and 55°C have been reported in the literature

length can be evaluated also by applying the methods presented here

A mo e-or less optimal mechanical performance of the bone prosthesis structure depends on an adequate set of structural parameter values This means that when some of these parameters are given quantities the others should be adapted to guarantee an adequate stress distribution On the one hand this implies that for instance prostheses made of titanium alloys with lower material stiffness require different stem designs than those fabricated with cobalt chromium alloys or ceramics on the other hand it is evident that patients with small bones require different prostheses than those having heavy bones It would thus be recommendable if several sizes of a certain prosthesis were available and a choice was made pre-operatively on the basis of roentgen measurements taking into account the concepts developed here (simple and rapid evaluation methods as the FEM beam model too could be useful in this procedure)

As mentioned previously the highest cement stress values occur on the proximal and distal sides close to the stem cement interface Since acrylic cement as present in the bone is many times weaker than industrial PMMA it would be advantageous to use pre polymerized plastic in these regions for instance by applying plastic coated stems and plastic rings at the proximal side

If a specific hip endoprosthesis is placed in valgus then apart from a possible influence on the joint loading the cement mantle thickness at the medial proximal side is increased so that the unphysiological radial and shear stresses on the cement bone interface as well as the hoop stresses in the bone at the calcar region are reduced It is remarkable that Bocco *et al* (1978) (see section I) found a significant reduction in the incidence of calcar resorption after placing the prostheses in valgus position Especially these remodeling and resorption phenomena including cement bone interface remodeling in relation with stress patterns present important and challenging research objects in the field of orthopedic biomechanics calling for detailed local stress analyses taking radiographically and histologically established tissue changes into account Since it is practically impossible to develop a model adequately refined to this end in a local sense which at the same time incorporates the whole structure the concepts and methods developed here provide a good basis for carrying out such analyses in two steps using the rough overall stress distribution as boundary conditions for a refined model of a detail of the structure

detailed and accurate stress analyses of intramedullary fixation structures Although useful in studying tendencies in a relative sense, provided certain precautions have been taken in the process of modeling, the visual apparent agreement between such a model and for instance an X ray of the structure, is often misleading
The mechanical conditions at the stem cement contact area that may slip and cannot transfer tensile stresses, have only a moderate influence on the mechanical performance of the structure in general, but a pronounced effect on the local stress distribution in the intermediate layer (the cement) and at the interfaces Hence, in detailed stress analyses these phenomena should certainly be taken into account
Composite beam theory as often used in the literature, is appropriate for the middle region only, to calculate stresses in the axial direction Where the cement layer is concerned however, the stresses in this region are quite insignificant compared to those in the proximal and distal regions
Based on the same concepts as the beams-on elastic foundation model (essentially assuming that both the bone and the stem behave in accordance with linear beam theory and the cement mantle as an elastic layer), a Finite Element Methods (FEM) beam model can be developed This model can take nonhomogeneous properties of the structure into account and may serve as a rapid, inexpensive evaluation method for the mechanical performance of specific stem designs in given bones under different circumstances

The maximal stem stresses occur roughly speaking, in the middle region the maximal cement and interface stresses at the proximal and distal sides in both cases at the stem cement interface (radial and shear stresses) The axial stresses in the bone are lower compared to the natural case, at the proximal side (the calcar region in the case of hip endoprostheses) quite unphysiological radial and shear stresses occur at the cement bone interface as well as hoop stresses in the bone
Immediately following the polymerization process the cooling acrylic cement will shrink around the stem leaving locked in stresses in the mantle These stresses will gradually relax, as can be concluded from relaxation tests decreasing by about 75% in 7 days However during the operation the generated hoop stresses may cause the cement mantle to fracture as can be concluded from approximative calculations using data on temperature distributions as evaluated in section II These stresses are maximal in the middle of the cement mantle so that tiny cracks may remain undetected

In using the fundamental concepts provided by the beams on elastic foundation analysis and applying the FEM beam model guidelines for stem designs and implantation procedures can be developed These guidelines are derived on the assumption that although the causes of bone remodeling phenomena are uncertain as yet a joint replacement will have less chances of failure if the stresses in the stem and the cement as well as the unphysiological stress components in and on the bone are reduced or at least smoothened as much as possible
From the approximative formulas it follows that on the proximal side the flexural and compressional stiffness of the stem should be as high as possible which implies a thick stem but retaining a cement layer of adequate thickness In the case of the hip endoprosthesis the layer thickness should be around 2 mm On the distal side the stem should be as flexible as possible, the intermediate layer as thick as possible Together these requirements point to a tapered stem The shape of the taper should not be an arbitrary one since it has a marked influence on the cement and stem stresses Using the FEM beam model this shape can be more or less optimized
The length of the stem, too has an optimal value that depends on the specific stem material properties its shape the cement properties and the properties of the bone An adequate

SUMMARY

It was the object of the studies described in this work to provide general fundamental concepts on some aspects of human joint replacement and the performance of artificial joints in the body
The work is divided into four sections of which the first discusses joint replacement and bone prosthesis structures in general In section II analyses of the process of heat generation and conduction in self curing acrylic cement as used for implant fixation are presented with the object of establishing the chances of thermal bone tissue necrosis and evaluating pre cautions that can be taken to prevent it. Section III is devoted to stress analyses of intra medullary fixation structures under loading with the object of determining the characteristic mechanical parameters of such structures evaluating their influences on the mechanical performance and providing guidelines for prosthesis designs and implantation procedures
In section IV some conclusions and recommendations as reached on the basis of the analyses are once more briefly discussed in general terms

Section I

Chapter 1 outlines some general aspects of artificial joint replacement The surgical procedure general requirements for implant designs and the features of commercially available types are briefly discussed Furthermore the physiological joint loading the properties of acrylic bone cement and bone remodeling phenomena are briefly described As in the greater part of this work the data are mainly focussed on the artificial hip joint
Chapter 2 gives an overview of a selection from the literature on postoperative complications especially artificial joint loosening and fracture
The objects and methods of the analyses fully treated in sections II and III are discussed in chapter 3
Besides providing data to be used in sections II and III and outlining the framework for the studies presented this section may serve as an introduction for those unacquainted with human joint replacement procedures

Section II

After a short introduction in chapter 1 a review of the literature on previous work as regards temperatures in self curing acrylic cement and its adjacent materials in bone-prosthesis structures is given in chapter 2 In chapter 3 too a literature review is presented this time as regards available data on thermal threshold levels of bone tissue necrosis
To evaluate the time dependent temperatures in the acrylic cement the implant and the bone during implant fixation theoretical models are applied the principles of which are presented in chapter 4 Parameter values that describe the thermal materials properties to

be used in the analyses are estimated on the basis of an extensive literature review, as discussed in chapter 5

The suitability of the method of analysis and the estimated parameter values are verified by simulating laboratory experiments, published in the literature, and by comparing calculated with measured temperatures, as shown in chapter 6

In chapter 7 a general model of an intramedullary fixation system is analysed Time dependent temperatures in the cement mantle, the prosthesis stem and the cortex of the bone are calculated In an extensive parametric analysis, the influences of the relevant geometrical thermal and compositional properties of the system on the temperature values are evaluated The effects of cement quantities used implant dimensions and vascular cooling are discussed Furthermore, the relevancy of using animal models to study thermal damage phenomena in this respect for human circumstances is investigated By comparing predicted bone temperature values with thermal damage threshold levels, the chances of bone tissue necrosis are estimated On combining results with those of relevant histological studies published in the literature, a hypothesis on the principal causes of the adverse side effects of acrylic cement evolves

Chapter 8 discusses an analysis of the process of heat generation and conduction during acetabular cup fixation Here, too, the occurrence of thermal damage to the bone at different locations is estimated

In chapter 9 the effectiveness of precautions that can be taken to reduce the temperatures are investigated Specific recommendations are made and simple graphs are presented for a rapid first order evaluation of the effect of several temperature reducing measures

Section III

After a short introduction in chapter 1 a review of the literature on stress analyses of bone prosthesis structures is presented in chapter 2 It is established that the available data on the mechanical performance of intramedullary fixation structures lack a general, fundamental basis To provide for this a simplified general model is analysed using different numerical and analytical methods This model is introduced in chapter 3 Results of strain gauge experiments on a cadaveric femur discussed briefly in chapter 4 serve as references for the analyses Different methods of analyses are applied and compared in chapter 5 Simple formulas are derived that approximate the most important stresses in the materials of the structure and at the contact regions as a function of the essential structural parameters A simple computer model is developed that can be used for inexpensive and rapid first-order evaluation of the mechanical performance of specific prosthesis stem designs in given bones The models used are based on assumptions and simplifications as regards the real structure, and the possible influences of neglected aspects are discussed in chapter 6 Attention is given to the occurrence of thermal locked in stresses in the cement mantle caused by shrinkage following the polymerization process the mechanical conditions of the stem cement and the cement bone contact regions (interfaces) more arbitrarily shaped stems and bones the influences of torsional loading on the prosthesis and a few others

Chapter 7 discusses the influences of the characteristic parameters of the stem the bone and the intermediate layer on the structural performance on the basis of parametric analyses using the fundamental concepts derived in chapter 5 combined with the different computer models

In chapter 8 guidelines for prosthesis designs and implantation procedures as follow from the analyses are given Several recommendations are made and in an example it is shown how, for a specific given bone an adequate stem design can be developed using the approximative formulas and the rapid evaluation computer model

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by

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MUNKSGAARD COPENHAGEN

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Preface

My teacher the late Wilhelm Anthonsen encouraged my interest in orthopaedic surgery for the treatment of the sequelae of neuromotor diseases This interest was further encouraged by a stimulating and extended visit in 1970 to Sheffield to Mr W J W Sharrard whose consistent application of the principles of muscle imbalance and the deforming forces has been an inspiration for so many orthopaedic surgeons Next came a stay in Toronto in 1971 with Professor R B Salter and Mr Norris Carroll Mr John Hall and Mr Mercer Rang where support was gained for a view of the dynamics of the hip not generally accepted at that time I am very grateful for the kindness extended and the instruction offered on these study tours

I wish to thank the Guildal Foundation and The Society and Home for Cripples Copenhagen for economic support for my travels

Encouragement to undertake these journeys and stimulating and provocative discussions of the orthopaedic problems in the treatment of patients with neuromotor disease were provided by Dr med Sven Brandt Lecturer Dr med Knud Jansen and Dr med Jorgen Saugmann Jensen who are thanked for their helpful contributions

Uncertainty as to the significance of the musculature for the stability of the hip was the soil which nourished the ideas underlying the present study These ideas started to germinate in 1969 in the course of the weekly clinics in the Outpatient Department for Handicapped Children the Rigshospital under the leadership of Professor Preben Plum I would like to thank him not only for his professional and personal stimulus but also for his never failing interest in the well being of the handicapped I like others owe Professor Plum a debt of gratitude for his contribution

The study was completed during my appointment in the Department of Orthopaedic Surgery U the Rigshospital from 1973 to 1978 I am very grateful to the head of the department Professor C C Arnoldi for the independent working conditions provided and for his support and criticism of the thesis and also because Professor Arnoldi has shown in writing and practice that the handicapped children must always have our support even though other important tasks also must be solved

The work could not have been completed without the splendid service provided by the personnel of the X ray archives and the secretaries at Ebberødgård the Children s Hospital in Vangede the Orthopaedic Hospital and the Rigshospital

The photographic department and the drawing office of the Rigshospital are also thanked for their professional assistance

The statisticians Dr J S Olsen and J Nyboe Actuary are thanked for discussions and advice on the statistical analysis of the results

H Cowan B Sc is thanked for the translation into English and for helpful linguistic discussions

The Danish Cerebral Palsy Foundation the Danish Medical Research Council and the P G Foundation have provided economic support in various phases of the work

The study was concluded in November 1977

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The extreme shows us
the way to the norm

Hypothesis

In the growing child there is a connection between the position of the head of the femur in relation to the acetabulum and the function of the surrounding muscles In particular it is the balance between the adductors and the abductors of the hip that is of significance for the stability of the hip in the frontal plane

Chapter I

Introduction

An attempt to understand the principles for the origin of the various deformities and their interrelations in children with neuromotor disturbances resulted in a paper on the static and dynamic problems when the patient is observed from the side (*Reimers* 1973b) The condition originally studied was spastic cerebral palsy but it was found that the principles demonstrated in the paper corresponded fully to what is known in the case of other although less deforming diseases

We know that the bones and joints are moulded by the influence of the surrounding musculature (*Wolff's Law*) and there is no reason to suppose that the bones and joints are concerned whether the cause of an altered muscular influence is of a neurogenic or of a primarily myogenic nature When therefore we wish to elucidate in the frontal plane some of the static and dynamic problems of the hip joint in childhood we may as well employ as a material children with pronounced deformities since by a study of the extreme we may learn something of the minor deviations from the norm

McKibbin (1970) stated that in congenital dislocation of the hip a sharp *distinction* should be drawn between the factors responsible for the initial *displacement* and *those influencing* the further progression This study will be concerned with an examination of the latter factors

The hip in myelomeningocele

To form an impression of what is already known on the subject of this study we *may* examine the hip in myelomeningocele as this condition gives a good picture of the *significance* of the surrounding muscles for the stability of the hip

Sharrard's study from 1964 has familiarized us with the segmental innervation of the *musculature of the* hip and lower limbs We may compare the normal picture with *that from* for example the study by *Carroll & Sharrard* (1972) of 88 hip joints in *children with* myelomeningocele which showed that when there was a nerve lesion at the level of L_I to L_{IV} the hip was found dislocated at birth in 40 per cent and 2 to 3 years later a further 15 per cent had developed dislocation If the nerve lesion lay *proximal* to L_I or was only found distal to L_I dislocation was more uncommon This implies that if only *the hip* flexors and adductors are functioning dislocation is common but if also these muscles are paralyzed or if there is increasing function of the hip abductors the frequency of dislocation diminishes

Menelaus in 1969 was of the opinion that the deforming force was essentially due to the hip flexors with or without active adductors but he also noted that the results following transposition of the iliopsoas as abductor would have been better if at the same time more adductor tenotomies had been performed

McKibbin (1973) stated that he only performed an adductor operation if it was necessary in order to reduce a hip in myelomeningocele To achieve retention of the hip he used a splint in abduction and possibly *psoas tenotomy*

Carroll & Sharrard (1972) *Rueda & Carroll* (1972) and *Sharrard* (1975b) emphasized the

The extreme shows us
the way to the norm

Hypothesis

In the growing child there is a connection between the position of the head of the femur in relation to the acetabulum and the function of the surrounding muscles In particular it is the balance between the adductors and the abductors of the hip that is of significance for the stability of the hip in the frontal plane

hips in the infant takes place too early after birth for which reason he advised against the prone position for infants and suggested instead that stimulation should be given to maintain flexion at the hip

Contrary to these proposals the work of *Michelsson & Langenskiold* (1972) carries conviction They showed that in one to five weeks old rabbits the hips dislocated if the knee joint was immobilized in extension for several weeks While so immobilized the animals maintained the corresponding hip in a flexed position If the hamstring muscles (Mm ischiocruralis) had been transected prior to the above neither dislocation nor dysplasia developed They drew an analogy with prenatal infants in the breech presentation where the hips can be flexed while the knees are extended and considered that in these cases the hamstrings could be the cause of dislocation of the hips *Fettweis* (1973) made a corresponding claim that of all the various delivery presentations only those children born in a frank breech presentation had a risk of hip dislocation as high as nine times that found in the other presentations since in the breech presentation the hamstrings exert pressure on the most posterior upper part of the acetabulum

Cardinet et al (1974) mentioned several studies which had pointed out the effect of pectineus tenotomy in dysplasia in dogs However they themselves found no unambiguous effect on extirpation of m pectineus possibly because the other adductors remained untreated

Electromyelographic and light microscopic studies by *Tonnis* (1969) showed no signs of disease of muscles or nerves in congenital dislocation of the hips Some minimal changes were interpreted as a sequela of inactivity *Matsoukas et al* (1969) on the other hand found that degenerative lesions were present in all cases of muscle biopsy from 67 children with dislocation of the hip the lesions being most pronounced in the younger children *Wolff & Tonnis* (1970) by electron microscopy of the muscles around the hip joint were unable to find any changes that could explain a muscular imbalance or the contractures in the adductors in congenital dislocation

It must be concluded from these studies that we are still unable to decide which muscles are of the greatest significance for the development of dislocation of the hip It is only when a knee is held artificially extended while simultaneously the hip is in flexion that we now know that the hamstrings are the deforming force With a valgus hip the hip abductors will function with reduced force and this in turn may result in a further valgus position

The »cerebral palsy« hip

*Silfverskjold*s study from 1924 and *Scheibel*s study from 1928 provide historical reviews of earlier treatment of the sequelae of cerebral palsy (*Little*s *disease*)

In 1836 *Strohmeyer* carried out a tenotomy on the tendo Achilles in the subsequent orthopaedic surgeon *J W Little* However it was not until 1880 that reports were published on the treatment of contractures at the hip when *Sayre Jr* reported at the Annual Meeting of the American Orthopedic Association that his father had treated adduction contractures for many years solely by clitorectomy and circumcision! In 1897 the same deformity was treated by *Lorenz* by means of obturator neurectomy

In 1907 *Ludloff* described a case of bilateral dislocation of the hip in a 6 year old girl with spastic paresis He pointed out that the acetabulum was less deformed than in congenital dislocation The hips could not be reduced and in his opinion the reason for the dislocation was spasticity in the adductors and flexors

In 1906 *Gaugele* proposed transection of the adductors and flexors but he was unable to reduce his three cases of dislocation He quoted a figure of 40 per cent for the incidence of

significance of starting with extensive adductor release before any possible further interven tion at the hip

London & Nichols (1975) reported that results were improved if transposition of the ad ductors was carried out before an operation upon the iliopsoas

Observations such as the above show that dislocation *may develop in association with* muscular imbalance around the hip joint

Opinions are divided however on whether it is imbalance between abductors and adduc tors or between flexors and extensors that has the greater significance

Experimental hip preparations

The literature does not seem to include any experimental studies on animals which might solve the problem raised above

Brooks & Wardle (1962) showed in experiments on 10 decalcified femora and hip joints that when the soft bones were exposed to load via the muscle preparations *the psoas muscle* deformed the neck of the femur into valgus position and the adductor magnus produced a varus position However they did not seem to take into account that the child is a growing individual and that the deforming effect on the epiphysis of the femur may release growth potentials which exert contrary effects

Bragard reached the same result in 1925 as a result of experiments with an apparatus in which the femur and hip were set up and a cordpull demonstrated the effect of the muscles on bones and joint He also found that theoretically the adductors should have a varus effect on the neck of the femur but accepted that in practice the adductors had a valgus effect in growing children

On the basis of experiments with a hip joint model consisting of a pelvis preparation with hip joint and femur in which the major muscle groups were replaced by chains with strain gauges *Merchant* (1965) found that the requirement for optimum functioning of the ab *ductors is a stable mobile and painless hip The force of the abductors should be adequate* and the length of the »lever« should be sufficiently long The femoral »lever« is the distance from the trochanter major to the axis for abduction and adduction running through the head of the femur the distance being measured at right angles to the direction of pull of the hip abductors (see Fig 13 p 61)

A valgus deformity of the neck of the femur is taken to signify that the angle between the body and neck of the femur is pathologically increased The angle may be determined on an antero posterior radiograph of the hip during maximum internal rotation so that any in creased anteversion is abolished *Inman* (1947) put forward the theory that coxa valga is due to subjects with paresis of the abductors putting an increased load over the hip As a conce quence the resultant of the forces acting on the head of the femur becomes more vertical and as the epiphyseal disc is at right angles to the forces acting on it the epiphysis becomes more horizontal with the result that a valgus hip develops In contrast to this theory *Rang (1969)* showed how a reduced *effect of the abductors could be considered to* result in re duced osteogenesis at the epiphysis of the trochanter major because of the diminished stimu lation by the muscles so that the valgus position is due to the absence of new bone

From experiments on rats *Sijbrandij* (1965) showed that the hip joint became dislocated if the hips were immobilized in the extended position and concluded that the extension of the hip *after* birth is of significance for the pathogenesis of dislocation The dislocating effect of the extension may be due to the iliopsoas as has also been suggested by *O Malley* (1965) and *Glauber et al* (1967) but in Sijbrandijs experiment the hips appear to have been adducted at the same time so it could also be that the absence of abduction was re sponsible for the deformity Among others *Fettweis* (1971) reported that extension of the

duction encouraging dislocation of the hip

Baker et al in 1962 wrote that every cerebral palsy patient should be considered until proved otherwise to have a hip problem and have early and repeated roentgenographic examination They recommended adductor and gracilis tenotomy with resection of the external obturator nerve as well as distal elongation of the hamstrings to retain the hip in position

Lamb & Pollock in 1962 considered that subluxation is due to weak abductors and extensors giving a tendency to coxa valga and that it is necessary to provide early treatment before an irreversible deformity has developed

A detailed bibliography was available in *Acta Orthopædica Belgica* (*29* 485 505) already in 1963 with 625 references to studies on cerebral palsy supplemented in 1967 by a further 90 references in *Revue de Chirurgie Orthopedique* (*53* 787 790)

Lewis et al in 1964 stated that in cerebral palsy abnormal muscular force influences the shape of the proximal part of the femur

Hagberg et al in 1964 analyzed a large material of 41 patients who had undergone intrapelvic obturator neurectomy for spasticity but unfortunately they did not report whether there were any effects on the hip joint

Samilson et al in 1967 analyzed a material of 105 children with cerebral palsy and low intelligence One conclusion was that after the age of 12 years a dislocated hip cannot be reduced by means of adductor tenotomy alone but femur osteotomy must be employed in addition

Smith in 1969 did not consider that the hip flexors play any major role in dislocation of the hip

Barry in 1969 considered the etiology of spastic dislocation as possibly due to an imbalance between the muscles around the hip joint especially between the abductors and adductors but he also considered that m gracilis and the hamstrings can be the main cause of the condition

Samilson et al in 1972 studied a material of 274 spastic patients with hip problems The dislocation of the hip was found to be due to retained neonatal reflexes muscular imbalance and contractures coxa valga with anteversion and a high acetabular angle

Fujiwara & Basmajian in 1974 also considered that stigmata of neurological immaturity may play a part in the dislocation of the hip They found in electromyographic studies that adductor activity in association with an underlying flexor activity is a possible dislocating factor

Feldkamp & Katthagen in 1975 showed that the stability of the hip is improved by lengthening the hamstrings However these operations were often combined simultaneously with adductor operations

Evans in 1975 stated that the cause of subluxation and dislocation in cerebral palsy must involve the hamstrings together with the gracilis and the other adductors

Sharrard et al in 1975 analyzed a treated and an untreated series of children with cerebral palsy All the children had reduced abduction and deformity at the hip as shown by radiography One of the conclusions reached was that normal hip abduction is possibly not the most significant factor when the aim is to achieve stability of the hip but that balance between abductors and adductors and between flexors and extensors is more suited to a maintenance of hip stability

Just as with the hip in myelomeningocele and in experimental preparations a review of the literature on the cerebral palsy hip has also been unable to decide the correctness of the hypothesis presented at the beginning of this study

All authors are of the opinion that experience and in a relatively few studies where objec

dislocation in cases of Little s disease *Wollenberg* in 1908 reported that *the dislocations* were produced by spasm in the adductors and *Weber* in 1911 found 4 cases of dislocation among 30 children with spastic palsy

Kunne in 1914 reviewed the histories of 23 diplegics 17 of whom had dislocation of the hips and he reported that paralysis of the hip abductors and external rotators produces »luxatio iliaca« and that paralysis of the adductors gives »luxatio infrapubica« As did *Feld kamp* later in 1976 *Kunne* described the asymmetrical abnormal position which develops when the child prefers to lie always on the same side so that the hip which is placed upper most is adducted and may dislocate *Samilson et al* in 1972 described the condition as »the wind blown hip« and *Fulford & Broun* (1976) called it »the windswept child«

Lange in 1921 on theoretical considerations concluded that the adductors must be the cause of coxa valga in spastic palsy

Watson Jones in 1926 was the first writer in the Anglo Saxon literature to present a case of »the very rare« combination of cerebral palsy and *dislocation of the hip He argued that* the primary cause was muscular imbalance with contracture in the adductors and of less significance also in the hip flexors As a result of resection of the n obturatorius and flexor tenotomy (without involving the psoas tendon) together with an abduction splint for 6 months his patient s hips became stabilized and the general condition improved

Klopfer in 1950 considered that in spastic diplegia the bones and in particular the aceta bulum are the site of an incomplete development (»status hypoplasticus«) and that in some cases this leads to dislocation In other cases the dislocation is due to a muscular imbalance

Mathews et al in 1953 claimed that dislocation of the hip had not been described pre viously in connection with cerebral palsy and proposed adductor operation with anterior n obturatorius resection as treatment

Mau in 1954 found that a valgus position was due to preponderance of adductors in re lation to abductors and recommended splinting in the abducted position He attempted to reduce dislocated hips in two cases without any improvement as both patients had consider able adduction contractures following treatment

Keats in 1957 recommended combined adductor and gracilis tenotomy with selective n obturatorius resection in correction of the adduction contractures

Pollock & Sharrard in 1958 found that in dislocation and subluxation adduction con tractures were always present but only half of the cases showed contractures of the flexors in addition At that time subluxations were not treated if it was felt that the child would not acquire any ability to ambulate

Phelps in 1959 considered that the cause of dislocation is coxa valga and contractures or spasticity in the adductors and gracilis Since a greater proportion of cases with coxa valga *were found among spastic children whose* legs were not exposed to weight bearing than among spastic children who could ambulate it was concluded that valgus develops as a re sult of absence of weight bearing by the legs

Le Cœur et al in 1959 claimed that dislocation is favoured by young age paralysis of the abductors and retention of abductor function in the opposite hip but that dislocation is provoked by the hamstrings

Banks & Green in 1960 recommended early operation and considered that operation on the adductors is to some extent preventive but *is also useful in dislocation* which is already present They combined treatment with obturator neurectomy

Plum in 1961 recommended resection of the n obturatorius for adduction contracture *but without mentioning* the possible effect on the hip

Jones in 1962 found that adduction increases the effective valgus position of the hip and recommended early varus osteotomy even in patients who would never be able to walk

Michele in 1962 considered that the iliopsoas produces an external rotation flexion ad

and after the operations (Migration Index) the Mann Whitney signed rank test was used A parametric test was used in determining correlation coefficients

As a rule collected data are quoted with a mean In the author s opinion this should only be done when the data are uniformly distributed But when the data are scanty and the range between greatest and smallest value is large the individual datum which deviates considerably from the mean will thus have too great a significance in deciding this In all cases therefore the median has been used instead (the mid value) corresponding to the 50 percentile

Age and time of observation are given in years^{months}

tive criteria are used the results demonstrate a relation between the stability of the hip and the function of the surrounding muscles Most are of the opinion that the factor leading to dislocation is imbalance between *the better functioning and possibly contracted* adductors including the m gracilis and the flexors Some few investigators claim that the hamstrings in their experience have a deforming effect

Review of the present investigation

In order to establish the hypothesis presented animal experiments could be carried out to produce muscular imbalance at the hip so as to analyze the dislocating effect of various muscle groups Alternatively it should be possible in children with cerebral palsy to provide treatment for corresponding imbalance between muscles and measure the results of treat ment on the hip joint by radiographic studies

Children may belong to the animal kingdom but not to the group in which experiments are permissible Operations have therefore not been performed with a view to furthering the investigation and the study has been restricted to a purely prospective recording of patients and surgical intervention since 1969 Apart from some few cases in the follow up of the re sults of operations on the hamstrings radiographic investigations have not been made with a direct view to the present study Such limitations have reduced the scope of the material very considerably

During the course of the work it was found necessary to solve several problems before the actual analysis of the muscle surgery could be done The result of the study has thus involved more than merely returning a »yes« or »no« to the hypothesis

First the measuring method had to be selected on the basis of the literature and the author s own investigations of the significance of rotation of the hip for the radiological pic ture of the stability of the hip Next it appeared that there was some uncertainty as to how *an optimal hip joint in childhood appears on the radiograph It was therefore necessary to* produce a series of »normal« hip joints and compare the results from this with those from the measuring method most commonly employed previously Following this it was possible to *establish definitions for the various degrees of hip deformation*

In order to demonstrate whether there was any possible effect of muscle surgery on the stability of the hip it was first necessary to examine whether the untreated cerebral palsy« hip undergoes a spontaneous lateral migration in relation to the acetabulum Next it was necessary to examine whether in fact any effect was actually achieved by soft tissue surgery and once this had been confirmed determine the magnitude of the result after one or more operations

Since adductor intervention is often combined with other soft tissue surgery other con secutive series had to be collected for the more uncommon isolated soft tissue operations and the results analyzed before this analysis could be made for the adductor operations

Finally a decision could be made on the question does contracture in the adductors have any significance as a deforming factor for the hip?

Treatment of data

The statistical analysis was carried out on the screen programmes of the Rigshospital

Non parametric tests were used to analyze the results In those cases were the stability (Migration Percentage) of the same hip could be measured before and after treatment the Wilcoxon test for paired differences was employed When it was a question of comparing non paired values as in measurements of the rate with which different hips migrated before

and after the operations (Migration Index) the Mann Whitney signed rank test was used A parametric test was used in determining correlation coefficients

As a rule collected data are quoted with a mean In the author s opinion this should only be done when the data are uniformly distributed But when the data are scanty and the range between greatest and smallest value is large the individual datum which deviates considerably from the mean will thus have too great a significance in deciding this In all cases therefore the median has been used instead (the mid value) corresponding to the 50 percentile

Age and time of observation are given in years$^{\text{months}}$

Chapter II

Measuring method

On a standard radiograph the method should provide a reproducible measurement for the position of the femoral head in the acetabulum without the measurement being affected by pelvic inclination (kyphosis lordosis) In addition the measurement should be possible by means of a simple measuring instrument

Methods

Hilgenreiner in 1925 introduced the *acetabular angle* (Fig 1) This angle is measured between the *Y line* (*Hilgenreiner s line*) and a line from the Y cartilage to the edge of the acetabulum The measurement is synonymous with the *acetabular index* introduced by *Kleinberg & Liebermann* in 1936 This is a frequently employed index and »normal series are available for age groups also beyond childhood (*Severin* 1941 *Massie & Howorth* 1950 *Caffey et al* 1956 *Harris et al* 1960 *Baker et al* 1962 and *Lusted & Keats* 1967)

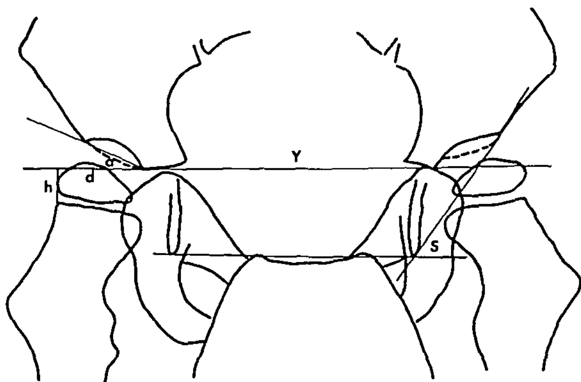


Figure 1
Right hip Hilgenreiner s three measurements in relation to the Y line a) The acetabular angle h) The least distance from the femoral diaphysis to the Y line d) Distance from the h line to the Y shaped cartilage
Left hip Sharp s acetabular angle marked S In contrast to Hilgenreiner s angle this angle is drawn in relation to the *U* figure

Ball & Kommenda (1968) and *Janotec* (1973) showed that the angle varies with the inclina tion of the pelvis The angle being greatest in kyphosis and smallest in lordosis for example as a result of hip flexion contracture which limits the applicability of the method *Lauren son* (1959) has provided a critical review of these topics

Sharp (1961) described another acetabular angle drawn between the distal tip of the U figure (pelvic tear drop) and the lateral edge of the acetabular roof This angle likewise provides an expression for the development of the acetabulum

Andren & Rosen (1958) claimed that hypoplasia of the acetabulum is the result and not the cause of congenital dislocation In experimental studies *Langenskiold et al* (1962) *Smith et al* (1963) *Bohr et al* (1965) and *Sybrandy* (1965) have shown that the acetabulum be comes hypoplastic as a consequence of dislocation of the femoral head In corresponding studies *Harris et al* (1975) showed that the acetabulum can become remodelled if reduc tion of the head is complete in children up to the age of four years It would therefore ap pear more logical to measure the position of the head in the acetabulum instead of measur ing the outcome of a suboptimal acetabular relation in the form of a hypoplasia of the ace tabulum

Already in 1925 *Hilgenreiner* pointed out that the most important sign of a threatening dis location is a separation of the femoral head from the acetabulum and that this can be de cided before the head is visible on an X ray The proximal displacement of the femoral head *is measured by the h distance* from the diaphysis of the femur to the Y line and *the lateral displacement by the d distance* from the femoral diaphysis to the acetabulum (Fig 1)

As there is a visible femoral head epiphysis already at the age of 7 months in 90 per cent of the hip joints (*Harris et al* 1960) there is no reason for using the above indirect method in the present study

Kemp & Boldero (1966) proposed as an expression for lateral displacement in Calve Legg Perthes disease the ratio of the least horizontal distance from the femoral head to the ace tabulum on the affected side to the corresponding distance on the healthy side *This index* can therefore only be used in unilateral changes

Shenton s line is an arc drawn on the radiograph from the lesser trochanter along the medial inferior surface of the femoral neck and joins the superior medial border of the obturator foramen Normally *this is a regular* smooth arc congrous on both sides (*Martin* 1951) A broken line expresses the proximal displacement of the femoral head and is included for example in *Trevor et al 3 point system* (1975) for evaluating the hip in childhood *Severin* (1941) regarded Shenton s line as a good indicator for static changes in the hip *Sharrard et al* (1975) stated that a break in the line indicates dysplasia

In contradistinction to these assumptions *Ball & Kommenda* (1968) showed experimen tally that Shenton s line is elevated in lordosis in adduction and in anteversion of the femur and the line is depressed in the opposite positions This excludes the possibility of using the method in children with hip flexion contracture for example

In 1939 *Wiberg* proposed the *CE angle* (CE = Centre Edge) measured between a line through the centre of the femoral head at right angles to the connecting line through the centres of both femoral heads and a line through the centre of the femoral head to the ace tabular edge The method was developed to apply to adults with the limitation that the CE angle is not suitable for any other pathological cases than the ones bordering on the normal

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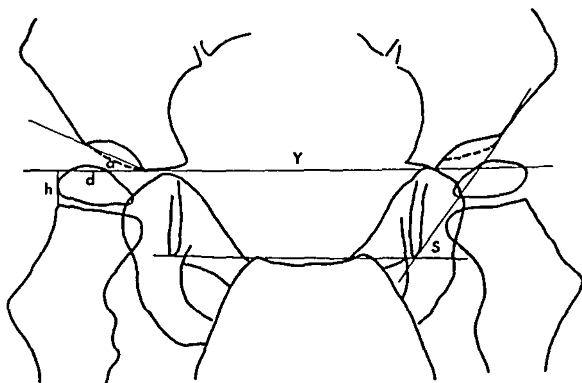


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the original one *Trevor et al* (1975) refer to *MacKenzie* and therefore presumably also use the modified angle This is probably also the case with the majority of recent authors employing this method

Another error of interpretation is found in the determination of the centre of the femoral head (*Sharp* 1961) In determining this centre a transparent ruler is used inscribed with concentric circles In adults and older children one of these circles is made to cover the head thus giving the centre At the same time one of the larger circles will be found to follow the acetabular curve In younger children or in cases of subluxation where the femoral head is often not circular the centre of the acetabular curve is used in practice a point which in younger children lies within the femoral diaphysis (*Massie & Howorth* 1950 *Wiberg* 1975)

A difficulty in determining the CE angle is that the edge of the acetabulum may be difficult to define particularly when there is lateral displacement of the femoral head where the border which is normally well marked is rounded and obtusely angled (*Ludloff* 1902 *Weber* 1911 *Putti* 1937 *Martin* 1951 *Hart* 1952 and *Bjerkreim* 1974a)

Heyman & Herndon (1950) and *Snyder* (1975) for example used the most lateral border of the acetabulum whereas *Harris et al* (1975) used the medial border when two boundaries were visible This implies that the lateral border of the acetabulum may be the subject of considerable subjective assessment (*Medbo* 1961)

Massie & Howorth (1950) stated that the CE angle is independent of abduction adduction or rotation of the femur since the centre will be the point around which the movement takes place so long as the femoral head is circular But the femoral head cannot be presupposed circular since it is the pathological hip joints whose evaluation we are interested in *Sharrard* (1969) pointed out that the centre for the movement of abduction adduction moves distally in the femoral diaphysis on subluxation of the head of the femur This was also pointed out by *Reimers* (1971 and 1973a) This means that on adduction of the femur a smaller part of the femoral head becomes covered by the acetabulum and as shown in Fig 3 abduction results in a larger part of the head being covered whereby the CE angle at the same time becomes larger



Figure 3
The same hip joint has been radiographed (a p view) in a) maximum internal rotation b) neutral rotation c) abduction
In abduction the femoral head migrates inwards in relation to Perkins line marked as a vertical line from the acetabular rim

Severin (1941) showed that *Wiberg's* normal series where a CE angle of more than 25° was found to be normal could be used down to the age of 18 years Severin added another normal material and found that a CE angle of at least 20° was normal for children between 6 years and 14 years

Massie & Howorth modified the method in 1950 so that the line through the centres was replaced by a line which is horizontal in relation to the pelvis as shown in Fig 2 They presented a normal material down to an age of 1 month but stated that the method was uncertain under the age of 3 years because the epiphysis of the femoral head might ossify irregularly (*Putti* 1937) They showed that a CE angle of at least 20° was normal from the age of 3 years and upwards

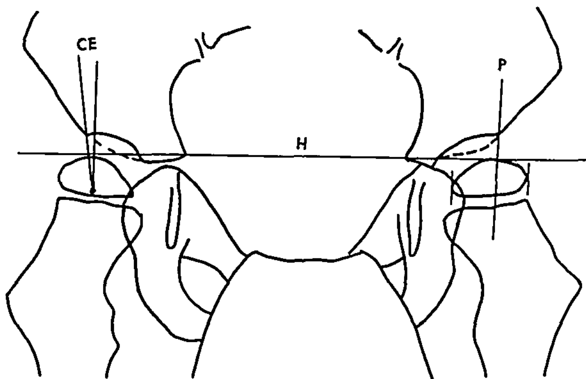


Figure 2
Right hip The modified CE angle where the vertical line is perpendicular to a line H which is horizontal in relation to the pelvis in distinction to the true CE angle where the vertical line is at right angles to a line joining the centres of the femoral head
Left hip P corresponds to Perkins line perpendicular to the horizontal line and passing through the acetabular edge

Lude & Taillard (1964) found a modified CE angle of 12° as a mean value by radiography of »normal« infant hips between the ages of 3 months and 2 years

Sharp (1961) pointed out that since the axis of the original CE angle has to go through the centres of both femoral heads false values are obtained when the contralateral hip is subluxated

Lequesne (1963) proposed the *VCE angle* where V indicates that the perpendicular line from the centre of the femoral head is vertical in relation to the pelvis corresponding to *Massie & Howard's* modification of the CE angle

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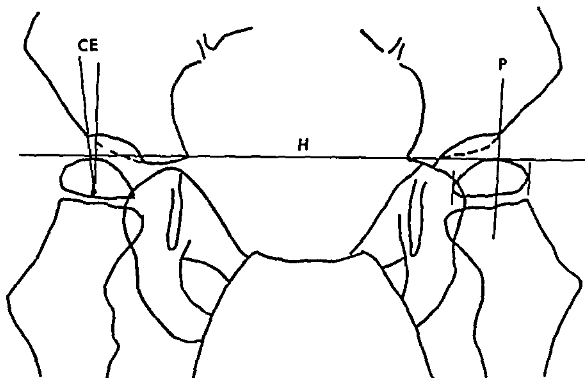


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those few which have really increased our knowledge of measurements of the femoral head in relation to the acetabulum

The acetabular angle (acetabular index) does not provide a direct measure of the placing of the femoral head in the acetabulum The CE angle and Perkins line on the contrary do provide this but in addition to the difficulty of an unambiguous definition of the acetabular border there is also the difficulty in the case of the CE angle of determining the centre of the femoral head

In describing the status of the hip therefore I have in the present study used Perkins line which runs from the lateral edge of the roof of the acetabulum We can then measure in the horizontal plane the part of the femoral head extending beyond the line and express this as a percentage of the entire width of the visible part of the femoral head likewise measured in the horizontal plane

A transparent ruler can be used for the measurement with a mm scale and with engraved transverse lines as shown in Fig 4



Figure 4
Measuring the migration percentage by means of a transparent ruler with transverse lines

By the use of this measuring instrument a measuring *error* of ± 0 5 mm is found for the smallest femoral heads measuring 5 mm corresponding to an uncertainty of at most ± 10% In larger children where more of the femoral head is visible on a radiograph the actual uncertainty becomes less but as the position of the acetabular edge may be difficult to define without ambiguity here too we must reckon with an uncertainty of ± 10%

In order to emphasize the dynamic element in the placing of the articular head the term Migration Percentage (MP) is used from an idea suggested by *Mercer Rang* (1975) indicating how large a part of the femoral head has migrated external to Perkins line

As early as 1928 *Mezzari* used the expression *la migrazione* to designate the variable relation of the femoral head to the acetabulum In the English literature *Mathews et al* used the expression in 1953

Perkins in 1928 described the line which bears his name The line was drawn from th prominent outer lower angle of the ilium (»anterior inferior spine«) at right angles to a h zontal line drawn between the innermost parts of the ilium at the Y shaped cartilage of acetabulum The placing of the femoral head can then be evaluated from these two lines shown in Fig 2

Perkins line is the same line as in *Puttis system* fra 1932 and *Ombredanne* in described a similar vertical line which bears his name in French and German literature corresponding line the *V line* was described by *Martin* in 1951

Medbo in 1961 measured in mm the part of the femoral head which projected b Perkins line The same measurement was made by *Zweymüller & Wicke* in 1973

Heyman & Herndon in 1950 defined an *Acetabulum Head Index* where the portion of the femoral head covered by the acetabular roof was divided by the width of the head and this fraction multiplied by 100 *Bellyet et al* (1975) recommended the method and re garded it as the most important prognostic sign in Legg Calve Perthes disease *Snyder* (1975) *used the percentage of subluxation* as measured by the proportion of the femoral head lying lateral to the lateral margin of the acetabulum

Schiller showed in 1972 that the advantage of measuring the relation of the head to the acetabular corner (= Perkins line) is that the measurements do not vary significantly in pel vic inclination (kyphosis lordosis) This also means that a urograph can be used with the beam centred in the mid line Schiller also showed that rotation of the pelvis around a ver tical axis, for example in unilateral atrophy of the gluteal muscles does not result in sig nificant changes in the measurements

In abduction adduction *of the femora the same considerations hold as in the case* of the CE angle (see Fig 3) so that the legs must be placed in the mid position during radio graphy

Just as in determining the CE angle there may be difficulty in an objective identification of the acetabular corner when the border is rounded In the present study the acetabular *corner is defined as the lateral edge of the roof of the acetabulum*

Rubens Duval et al in 1963 gave a system for measuring the statics of the hip joint by means of three angles and the ratio between two distances *This measuring method is completely* dependent on the rotation of the hip since the angulation of the neck and the projection of the axis of the neck in the acetabulum have a decisive significance for the result This method has therefore been rejected in the present study

Zsernaviczky & Turk in 1974 stated that in the normal hip in infants the centre of the femo ral head must lie on a straight line from the acetabular corner to the medial proximal edge of the diaphysis of the femur (*the Z line*) This measurement appears to be very accurate but only remains defined up to the age of one year so that *it cannot be employed here*

Many authors describe their own systems which are combinations of the methods men tioned and others but these are without interest for the present study *Smith et al* in *1968* developed an efficient system along known lines but like *Hilgenreiner* gave the distances to *the femoral diaphyses* Several authors use point systems based in part on the measuring methods mentioned *Trevor et al* in 1975 proposed a variation of the system of *MacKenzie et al* from 1960 their system including for example the CE angle Shenton s line pain mo bility and so on and is thus of no interest here

Conclusion

This review of the literature *has only included the most* important studies in particular

those few which have really increased our knowledge of measurements of the femoral head in relation to the acetabulum

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We know that the MP varies according to the degree of abduction adduction of the femur but we do not know what significance the rotation has for the measurements This must be examined therefore before it is possible to establish a standard for positioning the child for radiography

The significance of the hip rotation for the migration percentage

A priori one would not expect internal or external rotation of the femur to influence the relation of the femoral head to the acetabulum on a radiograph If it did so it would imply that the femoral head migrates inwards or outwards in the acetabulum for example when the hips rotate during walking

It is often reported that the hips have been positioned in »mean« rotation By this is meant that after having measured the maximum rotational mobility of the hip in simultaneous extension the leg has been positioned and immobilized midway between maximum internal and maximum external rotation This is presumably so as to ignore variations in the degree of anteversion If this procedure was to be carried out exactly it would be time consuming so that it must be considered that by »mean« rotation has been meant neutral rotation with patella pointing directly forward

Sharrard et al (1975) pointed out that they employed a position with the hips in »neutral *rotation and this is probably also the case with those authors who have not mentioned the* position adopted or have employed »standard« rotation *Fredensborg* (1975) measuring CE angles used the radiographs of the hips in children made by Dr Andren these films were taken under maximum internal rotation

A review of the literature suggests that the significance of rotation for the relation of femoral head and acetabulum has not been investigated It was therefore found necessary to examine this problem by measuring the MP in the same hip joint both during maximum internal rotation and in neutral rotation

Author's investigation

Previously it was the usual procedure to carry out a radiological examination of the hip joint in children in three projections maximum internal rotation neutral rotation and *Lauenstein s projection* also when it was only a question of evaluating the position of the femoral head in the acetabulum It was therefore possible among the examinations of children with cerebral palsy to find a sufficient number of older radiographs of the hip in

Table 1 Relation between migration percentage and hip rotation

n = 67	AGE years	MIGRATION PERCENTAGE per cent		r	P
		NEUTRAL ROTATION	INTERNAL ROTATION		
median	4[3]	19	15	0 88	< 0 001
range	1[3]-14[8]	0-38	0 45		

which the femoral head reached or passed Perkins line In all cases the rotation has been indicated on the film The individual measurements are seen in the table of raw data on p 78

Table 1 shows the result of the analysis There is a difference between the MP of 19 per cent in neutral rotation and the MP of 15 per cent in maximum internal rotation but the correlation coefficient r = 0 88 suggests a good relationship and the actual numerical difference is not particularly great

Discussion

As it was not considered justifiable to take radiographs as an aid to this study it is not certain that the films employed here have been taken precisely with the desired hip rotations On the other hand these are films made according to standard procedures so that the analysis may nevertheless be employed clinically

As mentioned it was not anticipated that a difference in MP would be found associated with different states of rotation of the hip One explanation for the difference found is that simultaneously with rotating the hip internally the patient lying in the supine position there is a tendency to abduct the hip a few degrees As a result the femoral head becomes more covered by the acetabulum so that the MP decreases

When a child with asymmetrical contractures of the musculature around the hip joints is allowed to take up a spontaneous position when lying supine i e when the child is allowed to place the legs as preferred a radiograph of the hip joints gives a more functional impression of the relation between the femoral head and the acetabulum However since the positioning of the head can vary from time to time the spontaneous position cannot be used as a standard method but only as a stage in a special investigation

Conclusion

The difference in the MP between the positions internal and neutral rotation is so small that in a radiological investigation of the MP of the hip the difference does not discriminate between the use of these positions

Radiological investigation of the stability of the hip joint

After this review of the literature and the author s own investigation it must be concluded that in a radiological investigation of the hip in children to evaluate the position of the visible part of the femoral head in relation to the acetabulum in the frontal plane the position of choice is with the child supine with the hip in the neutral position This is ensured by holding the knees together at the same level with the patellae pointing forward The beam of radiation should be centred vertically in the mid line of the body

Urography and colonic investigations can be used if the film shows that the femora and the hip joints are in the neutral abduction adduction position

The measurement used is the MP which indicates how large a part of the femoral head extends beyond Perkins line in proportion to the width of the entire head

We know that the MP varies according to the degree of abduction adduction of the femur but we do not know what significance the rotation has for the measurements This must be examined therefore before it is possible to establish a standard for positioning the child for radiography

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Table 2 Relation between CE angle and corresponding migration percentage

n = 125	AGE years	CE ANGLE degrees	MIGRATION PERCENTAGE per cent	r	P
median	5[2]	17	18	-0 76	< 0 001
range	1[10] 14[8]	38 0	0 47		

Table 2 summarizes the results and shows that there is a negative correlation between the CE angle and the MP with r = 0 76 where r is significantly different from 0 as P < 0 001

Conclusion

The *investigation supports Snyder s analysis As the correlation does* not permit normal values of CE angles to be converted to MP measurements it is therefore necessary to construct a new normal material of MPs

Preparation of a »normal material«

Medbo pointed out in 1965 that no great agreement existed in the literature as to what constituted the radiological picture of a normal hip in young children and he discussed the difficulties of defining what was normal

A few examples of material selected to represent normal hips will illustrate the problems involved

Wiberg s normal material from 1939 consisted of radiographs of the hip joint from 200 patients between 20 and 35 years of age without signs or symptoms of disease of the hip Wiberg pointed out however that they could develop signs or symptoms later

Sharp in 1961 defined a good hip as a joint which should last a man throughout his life time This normal material of Sharp s consisted of 100 patients over the age of 60 years without any signs of osteoarthrosis of the hip

The material of *Busse et al* in 1972 *consists* of randomly selected radiographs of 817 hips from persons over the age of 21 years The hip joints were presumably examined because of *symptoms originating here*

Severin s normal material from 1941 consisted of 200 hips *in which a radiograph had* been taken simply to be on the safe side These hips were normal according to the accepted standards The doubt expressed by Severin *as to the* justification of calling this a normal material appears from the uncertainty in setting up standards for normal

Massie & Howorth in 1950 used as their normal material a total of 300 hips from children with foot complaints but without *complaints* from the hip joints

Fredensborg in 1975 used the radiographs of the hips in 222 children as a control material for comparison with treated congenital hip dislocations *The control* radiographs had been made because the children had been exposed to trauma or had intermittent hip pain

For ethical reasons a material of radiographs of normal hips in children cannot be presented The known series are *therefore* based on selected patient groups and can only tell us the state of the hip in the disease in question

Chapter III

»Normal material«

The literature was reviewed but without success for a »normal material« of children s hips measured with reference to Perkins line or to the acetabular edge

Perkins in 1928 stated that in children under the age of 4 years the femoral head rarely reached the line but he did not document this claim *Ombredanne* in 1932 stated that the *normal hip in children lay within the vertical line from the border of the acetabulum* *Putti* made the same claim in 1932 and *Doberti & Manhood* confirmed this in 1968 *Martin* re ported in 1951 that the femoral diaphysis lay within the V line (= Perkins line) *Hart* in 1952 stated that in the normal hip in children the visible part of the femoral head always lies within Perkins line However *Ingram & Farrar* in 1955 stated that in the normal hip at *least 60 per cent of the epiphysis of the femoral head should be medial to the line*

Medbo in 1961 stated that all children s hips lying medial to the line are »normal and those hips that are 0-2 mm lateral to the line are »normal?« *Sharrard et al* in 1975 stated that the visible part of the femoral head is completely covered by the acetabulum when the hip is normal but on an accompanying radiograph reported to be of a normal hip part of the femoral head is seen external to the acetabular rim

In contrast to these reports several normal series of CE angles are available for various ages and if a total correlation existed between the CE angle and the MP for the same hip then one of these series of observations could be used for conversion to MPs

Relation between CE angle and migration percentage

Snyder in 1975 found that the correlation between the percentage of subluxation (= MP) and CE angle was negative with r = 0 77 As the details in the analysis are not provided and as the investigation does not appear to have been repeated by other investigators it has been found necessary to do so before possibly rejecting the use of a normal material of CE angles

Author's investigation

In order to find a satisfactory number of pathological hip joints a search was made for material among children with cerebral palsy Among these radiographs of 123 hips have been selected where the femoral head has either reached Perkins line or has migrated beyond this line

The CE angle was measured by M E Muller s goniometer (PROTEK AG BERN) in relation to a horizontal line through the pelvis as this modification of the angle is most commonly employed The individual results are shown in the tables of raw data on pages 79 and 80

among the first 50 per cent of the most stable hip joints there are nevertheless femoral heads which project 5 per cent beyond the line

Corresponding to the 50 percentile line (the median) there is a significant increase in the MP from the first to the third age group but no significant change in MP from the third to the fourth age group

Discussion

The result of the investigation corresponds to the experience of Perkins that the femoral head is completely covered by the acetabulum in children under the age of 4 years The few hips in which the femoral head extended beyond the line before the age of 4 years are per haps normal but hardly »optimal

Even though the material is cleared for children with diseases which we know result in less than perfect hip joints it is the case for all patients in this investigation that they had a manifest or suspected urological disease The material is therefore dominated by children whose hip joints are presumably less normal that they would have been if the children had been well

The investigation therefore does not provide an expression for normality but should rather be considered as indicating the optimal placing of the femoral head in relation to Perkins line

In this investigation all the femoral heads which lay completely within Perkins line have been given the MP value 0 per cent It will of course also be possible to indicate how deeply the femoral head is lying in relation to the acetabulum by measuring the distance from the caput femoris out to Perkins line and give this result as a percentage of the entire width of the femoral head but with a negative *sign* *However* this parameter has not been included in the present study Nevertheless a limit must be found for the permissible depth of the fe moral head before it is no longer placed optimally but passes instead into the *pathological* condition protrusio acetabuli which results in osteoarthrosis (*Friedenberg* 1963 and *Hoo per & Jones* 1971)

Morzlle in 1933 was one of the authors to point out that the incongruent hip could develop into malum coxae senile – osteoarthrosis *Wiberg* in 1939 showed that a sub luxated hip could lead to coxarthrosis *Bjerkreim* (1974b) showed how pronounced dysplasia of the hip in association with an oblique pelvis gave the same malformation

Following up treated cases of dislocation of the hip *Smith et al* among others showed in 1968 that poor reduction as evaluated on the radiograph resulted in osteoarthrosis Con versely *Albert* in 1952 and *Busse et al* in 1972 showed that the hip joint with osteoarthrosis has a smaller CE angle than the hip joint without any sign of this but these authors do not discuss whether the smaller CE angle might be secondary to a lateralization of the femoral head as a result of the osteoarthrosis

The literature does not indicate how much or how little of the femoral head must lie out side Perkins line in childhood before the condition results in osteoarthrosis in the adult sub ject Before this question is investigated the optimal hip cannot be delimited with cer tainty

Conclusion

In children under the age of 4 years the observation that the femoral head was completely covered by the acetabulum in 102 out of 109 hip joints indicates that Perkins line repre sents the maximum lateral position for the femoral head in the »optimal hip *In children* between the ages of 4 and 16 years at most 5 per cent of the visible part of the femoral head

It would be more useful to know how that hip appears in childhood which is to serve the subject free from symptoms throughout life in other words the »optimal« hip

The complex function of the hip joint cannot be described exhaustively by means of a single variable only In the present study this variable is the placement of the femoral head below the acetabulum as measured on an a p radiograph Experience shows however that this is the radiographic examination which with the least radiation dose gives the maximum amount of information on hip function *provided that mobility is adequate and painless*

Author's investigation

Urographic studies made in childhood usually also show the hip joints and as the MP can also be measured on these films this material has been selected as a starting point for the investigation

Many hundred urographs from Radiological Department X of the Rigshospital were examined and the hips measured From this material all patients were excluded with visible deformities of the pelvis and vertebral column including spina bifida Next all patients were excluded with Wilms tumour and neuromuscular diseases for example cerebral palsy Only those hip joints were included which had been placed in the neutral abduction adduction position during the radiological investigation

After measuring the MP the case records were reviewed for those patients in whom the femoral head projected beyond Perkins line *As a result of this review it became clear that* a large proportion of these patients had had urinary tract infection as a result of congenital malformations since the first year of life for which reason this group of patients was also excluded There remained nevertheless a number of hip joints in which the femoral head was placed laterally in the acetabulum *with squeezed acetabular rim a breach in Shenton s line* and small CE angle etc without it being possible to find a medical etiology for this so that they were retained in the material The total remaining 355 measurements are tabulated in the Table on p 80

Table 3 Migration percentage of 355 hip joints on urographs from »normal« children

AGE years	n	MIGRATION PERCENTAGE per cent PERCENTILES 10	50	90	100	P
< 4	108	0	0	0	14	< 0 01
4 ≤ - < 8	126	0	0	10	29	< 0 01
8 ≤ - < 12	78	0	5	12	16	> 0 05
12 ≤ - < 16	43	0	5	13	18	

Table 3 summarizes and sets out the measurements in percentiles The results are grouped into 4 year groups as a closer differentiation is not justifiable since the bone age was not determined The Table shows that in children under the age of 4 years *that part of the femoral head* visible on a radiograph is completely covered by the acetabulum in at least 90 per cent of the hip joints Among children older than 4 years at least 10 per cent (actually 37 per cent) of the total number of femoral heads are completely *within Perkins line* but

among the first 50 per cent of the most stable hip joints there are nevertheless femoral heads which project 5 per cent beyond the line

Corresponding to the 50 percentile line (the median) there is a significant increase in the MP from the first to the third age group but no significant change in MP from the third to the fourth age group

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The literature does not indicate how much or how little of the femoral head must lie outside Perkins line in childhood before the condition results in osteoarthrosis in the adult subject Before this question is investigated the optimal hip cannot be delimited with certainty

Conclusion

In children under the age of 4 years the observation that the femoral head was completely covered by the acetabulum in 102 out of 108 *hip* joints indicates that Perkins line represents the maximum lateral position for the femoral head in the optimal hip In children between the ages of 4 and 16 years at most 5 *per cent of the* visible part of the femoral head

It would be more useful to know how that hip appears in childhood which is to serve the subject free from symptoms throughout life in other words the »optimal« hip

The complex function of the hip joint cannot be described exhaustively by means of a *single variable only In the present study this variable is the placement of the femoral head* below the acetabulum as measured on an a p radiograph Experience shows however that this is the radiographic examination which with the least radiation dose gives the maximum amount of information on hip function provided that mobility is adequate and painless

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is lateral to Perkins line in the »optimal« hip this being the finding in 159 out of 247 hips i e not quite ⅔ This concept is only a provisional one i e until we know more about the relation between the MP and coxarthrosis

Comparison between »normal« and »abnormal« CE angles and migration percentages

In Chapter II a correlation was found between the CE angle of the hip and the MP with r = -0 76 Having now prepared a »normal material for the MP of the hip in childhood it would be interesting to compare this material with a »normal material« based on CE angles to determine whether within the latter s limits for »normal« there is a correlation with »normal« MP and thus determine whether in spite of sources of error the CE angle can be used in childhood

Author's investigation

Massie & Howorth (1950) used the same modified CE angle as that used here These authors *stated that the CE angle can be used right down to the age of 3 years and in their large* »normal material« they found that the hip was normal when the CE angle was ≥ 20° for the age of 3 years and upwards

Using the same material as employed in Table 2 (raw data on pages 79 and 80) the associated values can be obtained for CE angle and MP in children over the age of 3 years

Table 4 Comparison between normal CE angles ≥ 20 degrees and »abnormal CE angles < 20 degrees and corresponding migration percentage

HIP JOINTS	n		AGE ≥ 3 years	CE ANGLE degrees	MIGRATION PERCENTAGE ≥ 0	r	P
»normal«	37	median range	5^9 3^5-14^6	25 38-20	12 0 22	0 282	0 085
»abnormal	66	median range	5^7 3^2-11^2	15 19 0	21 0 47	0 850	< 0 001

Table 4 shows that the age is the same in the two groups of CE angles normal« and abnormal« In the group with Massie & Howorth s normal hips with a CE angle ≥ 20° the correlation between CE angle and *MP is very poor* whereas in the group with »abnormal hips with a CE angle < 20° the correlation gives the same value as that found for the entire material of Table 2

In the group with CE angles ≥ 20° there are hips with a MP up to 22 per cent which according to Table 3 cannot even be described as normal and *on the basis of the conclu sion* on p 23 even less called »optimal« In the group with CE angles < 20° it appears that in only one hip the corresponding MP is 0 per cent In the rest of the hips the MPs are at least 4 per cent which corresponds to the upper limit for the »optimal hips in children above the age of 4 years

Conclusion

A comparison between measurements of the same hip joints using CE angles and MP gave as result that a CE angle < 20° indicates that the the hip in a child above the age of 4 years is not optimal On the other hand it is not possible with certainty to come to any conclusion with regard to the stability of the hip in childhood when the CE angle ≥ 20° Correspond ing to that uncertainty the correlation between the CE angles ≥ 20° and the MP is poor

Definitions

In the literature the terms dislocation and luxation signify that the femoral head has no contact with the acetabulum (*MacKenzie et al* 1960 *Smith et al* 1968 *Samilson et al* 1972 and *Sharrard et al* 1975) However dislocation may also designate all degrees of lateraliza tion of the femoral head (*Harris et al* 1960)

Subluxation is most often defined as the condition in which at least one third of the femoral head lies external to the acetabulum (*Sharrard et al* 1975) Others however have laid down the requirement that this should be evaluated on an arthrogram (*Samilson et al* 1972)

Severin (1941) used the term subluxation only when the CE angle was negative corre sponding to the situation in which half of the femoral head lay beyond the acetabular corner *Bjerkreim* (1974a) and *Snyder* (1975) used the term subluxation for any protrusion of the femoral head beyond the acetabulum but where contact with it was still maintained *Baker et al* (1962) classified subluxation into three degrees in which III° corresponds with dislocation

Dysplasia may be taken to signify that the hip joint as a whole has an abnormal appear ance on a radiograph (*Wiberg* 1939 and *Baacke & Tonnis* 1974) *Medbo* (1961) used the term to signify that the femoral head extends more than 5 mm beyond the acetabulum In the study by *Sharrard et al* (1975) the term signifies that more than two thirds of the femoral head is covered by the acetabulum but with other abnormalities Dysplasia is most often used to signify a steep acetabular roof (*Sharp* 1961 *Baker et al* 1962 *Bjerkreim* 1974a and *Zsernaviczky & Turk* 1974) or all the sequelae of a subluxation (*Salter* 1970)

Discussion

It appears from the above remarks that the terms dislocation luxation subluxation and dysplasia are employed with varying meanings and often without being clearly defined

In children with neuromotor disease and clinically dislocated hip joints contact with the acetabulum often is maintained medially on the radiograph When the dislocation is acquired the acetabular deformation will develop so slowly that its shape alters in parallel with the migration of the femoral head Dislocations of this kind therefore do not always satisfy the requirement that there should be a lack of contact with the acetabulum

In the terminology of descriptive radiographic diagnosis of the containment of children s hip joints the terms nothing abnormal and normal are included These terms are like wise not defined unambiguously

It might be more relevant to describe the containment by the MP instead of the usual type of diagnosis It would thus be unnecessary to procure any available earlier radiographs in order to make a comparison with the new X ray but merely to compare MPs

Conclusion

Migration Percentage (MP) signifies the fraction (expressed in per cent) of the visible part of the femoral head which on an a p radiograph has migrated beyond Perkins line (= aceta bular rim) The measurements are made along a line horizontal to the pelvis

Migration is defined as the difference between two instantaneous MPs determined at two different times

Subluxation signifies that the MP is at least 33 per cent

Dislocation signifies that the MP is 100 per cent

Dysplasia is the term used during the period before the femoral head has become visible and signifies that the acetabulum is sloping with a retreating border as if it had been squeezed during growth

Recording the migration

Massie & Howorth noted in 1950 that »no roentgenographic measurement is a mathematical certainty because slight positional variations affect the readings« This still holds and has not been refuted in the preceding sections

To facilitate identifying those cases where a radiograph has been made although the hips have not been in the neutral abduction adduction position all the courses of the migration of the hips which constitute a basis for the subsequent analyses have been recorded in a co ordinate system A recording of this kind may also be used to obtain an impression of the prognosis for the migration of the hip

In Fig 5 the abscissa is time and the ordinate is MP The figure presents graphically a partly hypothetical example of the course of the migration of the hips in a child with cere bral palsy At the first radiographic examination in 1968 both femoral heads were com pletely covered by the acetabulum By 1969 both hips had drifted outwards so that 24 per

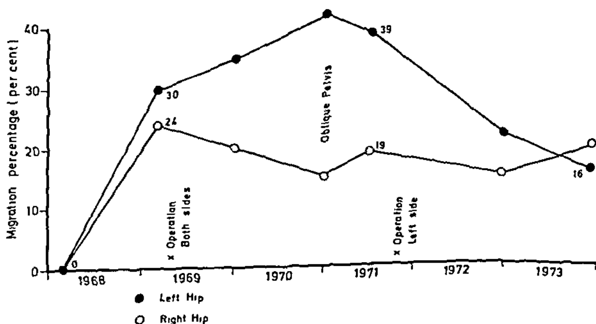


Figure 5
Migration percentage in relation to time before and after operations in a hypothetical case

cent of the right femoral head and 30 per cent of the left femoral head had moved beyond Perkins line As a result of the operation which followed the MP of the hips were altered The right hip moved inwards and the left hip moved slowly outwards The MP remained divergent until the middle of 1971 at which time the MPs were 19 per cent and 39 per cent

When the hips show a change in direction on the curve without preceding treatment the MPs beginning to converge instead of diverge this usually means that the more divergent measurements have been made with the pelvis oblique In the present case the right hip has been abducted and the left hip adducted for which reason no value can be attached to such a measurement However there may be such pronounced contractures in the abductors or adductors that the pelvis cannot be placed in a neutral position Such faulty positions will not be noticed on the curves as no change will be observed in the slope of the curves so long as the contractures remain untreated Measurements from such records are not rejected

Following the next operation this time on the left hip this hip too moved inwards and in 1973 was found to have a MP of 16 per cent

In order to visualize those changes in the MP of the hips resulting from treatment a coordinate system may be used with the same units in both coordinates (*Freeman et al* 1973 and *Collert* 1974)

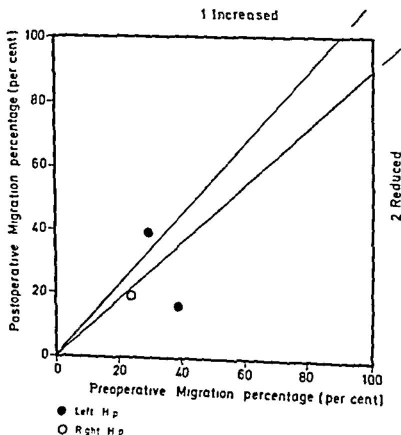


Figure 6
Diagram illustrating the difference in migration percentage before and after the operations in Fig 5

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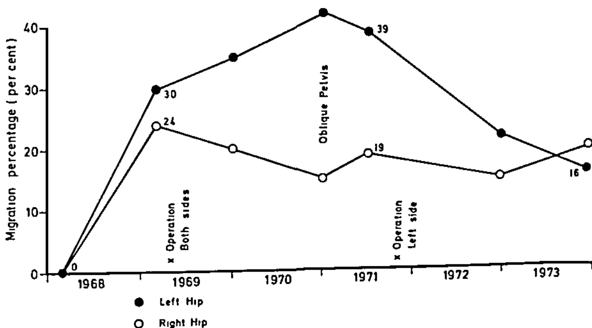


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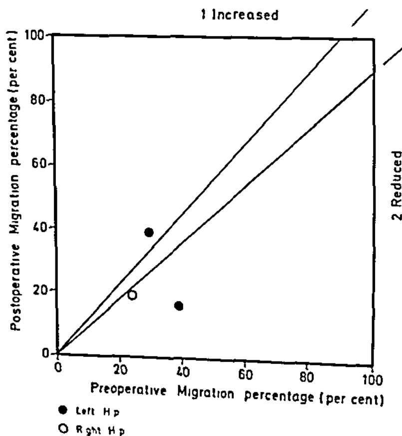


Figure 6
Diagram illustrating the difference in migration percentage before and after the operations in Fig 5

In Fig 6 the MPs have been inserted for the two hip joints from the above example just before the three operations and on follow up examination or just before the next operation *It is obvious that the coordinate area is divided into two regions the upper including all hips* where there has been an increase in MP the lower all hips where there has been a reduction in MP To make allowance for uncertainty in the results the diagonal separating the two regions is replaced by two lines embracing an area of ± 10 per cent of the actual values obtained

Fig 6 shows that the right hip lies in the region of reduced MP as the MP in 1969 was 24 per cent and post operatively just before the next operation i 1971 it was 19 per cent The left hip lies both in the upper region as the MP had increased in spite of the treatment in 1969 and in the lower region corresponding to the result of reoperation in 1971

The constructed example shows changes in MP from just before to just after the operation The diagram can be used in a similar manner to illustrate the course of hip migration either before or after operation (Fig 5 shows that before the right hip was operated on the MP changed from 0 per cent to 24 per cent and after operation from 24 per cent to 19 per cent) Both methods of representation will be used in the next section

Chapter IV

Spontaneous migration

One aim of this study is to examine whether subluxation of the hip joint in cerebral palsy is most frequently an acquired condition This presupposes that the spontaneous migration of the normal hip is known and that subluxation does not occur in the normal hip

The »normal« hip

The spontaneous migration occurring throughout the years of childhood can be seen directly from Table 3 This normal material shows that the median (the 50 percentile) value of the MP varies from 0 per cent in children under the age of 4 years to 5 per cent in children betwen 12 years and 16 years The difference is significant Table 3 also shows that none of the 355 hip joints were found subluxated

Conclusion

The migration of the normal hip in children is less than 1 per cent per annum The normal hip in children does not undergo subluxation

The »cerebral-palsy« hip

Since *Ludloff* in 1902 described a case of bilateral dislocation of the hip in a girl with Little's disease the subject has been often discussed *Wollenberg* in 1908 stated that it was difficult to demonstrate that the dislocation is a direct sequela to cerebral palsy However the literature contains terms such as dislocating luxating subluxating and *migrating hips* as an indication that experience has made it clear that subluxation and dislocation may be acquired The same is suggested by the many communications on the causes of dislocation (e g *Klopfer* 1950 *Mau* 1951 *Phelps* 1959 *Lamp & Pollock* 1962) and on its prophylaxis (e g *Caugele* 1906 *Pollock & Sharrard* 1958 *Bank & Green* 1960 and *Jones* 1962)

In spite of the many investigations carried out it has not been possible to find one study which provides proof that the subluxated hip in cerebral palsy is in fact acquired and not a congenital deformity

Author's investigation

Surgical treatment of the sequelae of cerebral palsy was carried out in the case of 441 patients admitted to Department I of the Orthopaedic Hospital Copenhagen during the period 1st January 1969 to 1st July 1971 In this total there were 127 children under the age of 19 years who underwent a total of 218 adductor operations during the period possibly combined with other operations but exclusive of operations on the hamstrings or osteotomy

of the femur Among these 127 children there were a total of 38 children who within the period mentioned had had a MP of at least 33 per cent (= subluxation) in one or both hips

Based on radiographs from a number of hospitals and institutions curves were drawn of the course of hip migration Any operations on the adductors prior to 1969 were included in the investigation

In 39 cases out of 63 first time operations on the adductors not only was a usable radio graph of the hip found preoperatively but also at least 3 months prior to this so that the preoperative migration of the untreated hips could be recorded on a diagram as shown in Fig 7 In this investigation the earliest radiograph which could be traced was used (raw data on p 81)

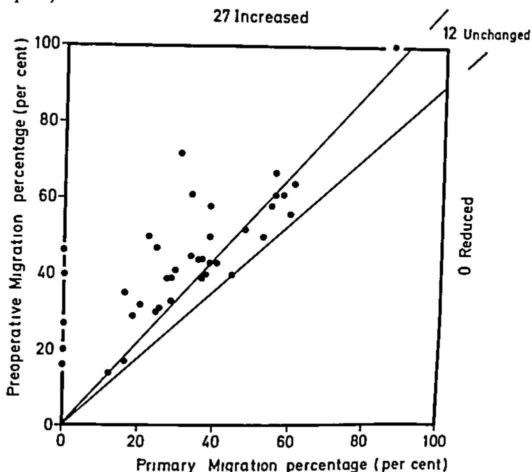


Figure 7
Spontaneous migration of 39 cerebral palsy hips

Fig 7 shows that 27 hips had migrated outwards in relation to Perkins line 12 hips had re mained unchanged and no hips had migrated inwards

From the time the primary radiograph of the hips was made to the time the preoperative radiological investigation was performed 5 hips which primarily had been completely covered by the acetabulum had migrated beyond Perkins line 16 per cent 20 27 40 and 46 per cent respectively while 10 hips had become subluxated and 1 hip had become dis located

Table 5 summarizes the MPs for all 39 hips The table shows that the median value for the MP on the primary radiograph was 33 per cent and just before the first adductor operation it was 43 per cent This difference is significant with $P < 0.001$ The period of observation had a median value of 1 year

Table 5 Migration percentage before first operation on the adductors

n = 39	OBSERVATION years	MIGRATION PERCENTAGE per cent	
	PREOP	PRIM	PREOP
median	1	33	45
range	0³ 14	0 86	14 100

P < 0 001

Conclusion

In agreement with clinical experience the investigation shows that the subluxated hip in cerebral palsy is most often acquired since 1) the spontaneous migration of approximately 10 per cent per annum is significantly greater than the migration of less than 1 per cent per annum in the case of the normal hip 2) of the total of 30 hips which were subluxated at the time of operation 10 of the hips had subluxated during the course of the period of observation a median interval of 1 year 3) the normal hip does not subluxate 4) none of the cerebral palsy hips improved spontaneously

Postoperative migration

The »cerebral palsy« hip

The literature has often described how the femoral head may migrate inwards following operations on muscles and tendons (e g *Watson Jones* 1926 *Banks & Green* 1960 *Baker et al* 1962 *Samilson et al* 1967 *Ingram* 1971 *Samilson et al* 1972 and *Sharrard et al* 1975) These accounts however have not demonstrated at the same time that it was the hip joint which previously migrating outwards had now improved after and possibly as a result of the operations *Sharrard et al* (1975) however did mention that subluxations could arise during the waiting period prior to admission for operation

Before analyzing in further detail the separate factors influencing the position of the hip in the acetabulum there are therefore grounds for demonstrating that alone by surgery of muscles and tendons it is possible to influence the MP and to show the degree to which this is possible

The effect of first operation on the adductors

In the present material adductor surgery is performed through a transverse incision in the groin over the adductor longus tendon The tendons and muscles of the adductors are divided proximally so that all structures are transected which hinder normal abduction with the hip both flexed and extended The operation also often includes tenotomy of the m gracilis in the groin or resection proximal to the knee If the spasticity has been pro nounced in the adductors the anterior branch of the obturator nerve is resected and where important hip flexion contracture has been found preoperatively the iliopsoas is also di

of the femur Among these 127 children there were a total of 38 children who within the period mentioned had had a MP of at least 33 per cent (= subluxation) in one or both hips

Based on radiographs from a number of hospitals and institutions curves were drawn of the course of hip migration Any operations on the adductors prior to 1969 were included in the investigation

In 39 cases out of 63 first time operations on the adductors not only was a usable radio graph of the hip found preoperatively but also at least 3 months prior to this so that the preoperative migration of the untreated hips could be recorded on a diagram as shown in Fig 7 In this investigation the earliest radiograph which could be traced was used (raw data on p 81)

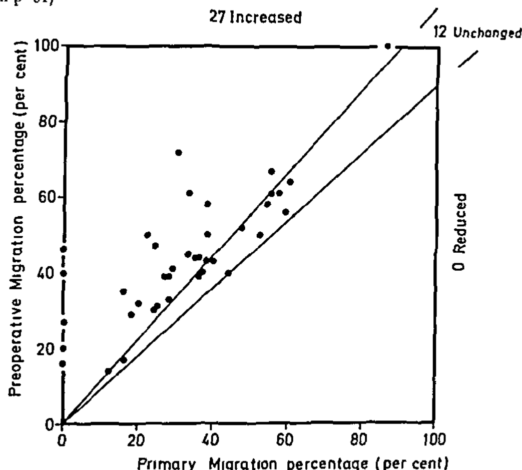


Figure 7
Spontaneous migration of 39 cerebral palsy hips

Fig 7 shows that 27 hips had migrated outwards in relation to Perkins line 12 hips had re mained unchanged and no hips had migrated inwards

From the time the primary radiograph of the hips was made to the time the preoperative radiological investigation was performed 5 hips which primarily had been completely covered by the acetabulum had migrated beyond Perkins line 16 per cent 20 27 40 and 46 per cent respectively while 10 hips had become subluxated and 1 hip had become dis located

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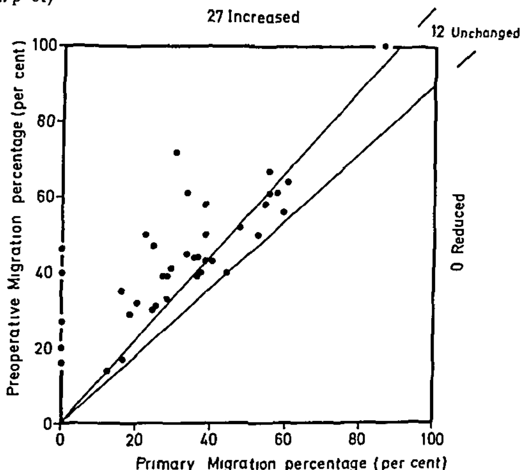


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vided near the attachment to the trochanter minor Postoperatively the patients were immobilized in abduction in a plaster cast for 3 weeks followed by night splinting in abduction

Author's investigation

The same material of »cerebral palsy« hips in which the spontaneous migration was demonstrated was subjected to measurement following the operation The hips were measured on the latest useful radiograph prior to any possible subsequent operation and latest on the 1st November 1973 which was selected as the termination date of the investigation (raw data on p 81)

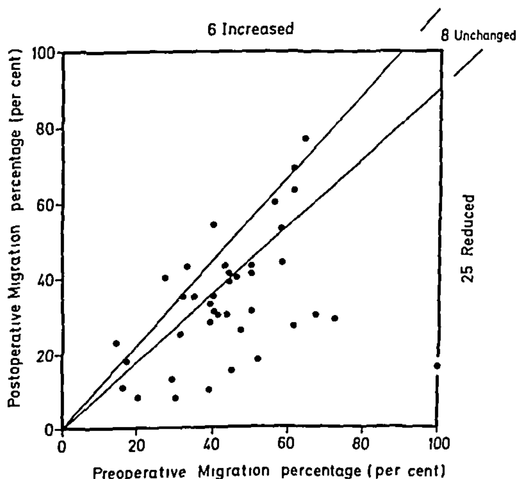


Figure 8
Migration of 39 cerebral palsy hips after first operation on the adductors

Fig 8 shows that after the operation the MP was reduced in 25 of the hips 8 of the hips were unchanged and 6 of them had an increased MP The hip which was previously dislocated had been reduced as a result of operation so that only 18 per cent of the femoral head now reached beyond Perkins line The figure also shows that the improvement was distributed uniformly and did not apply only to the subluxated hips with a MP of at least 33 per cent A comparison with Fig 7 shows immediately that the operation has influenced the migration in a favourable direction

Table 6 Migration percentage before and after first operation on the adductors with preoperative observation

n = 39	MIGRATION PERCENTAGE per cent		
	PRIM	PREOP	POSTOP
median	35	45	31
range	0 86	14 100	8 77

P < 0 001   P < 0 001

Table 6 summarizes the MPs of the hips before and after operation Following the operation the median value of the MP decreased from a preoperative value of 45 per cent to a post operative value of 31 per cent This corresponds to a migration before operation of 10 per cent outwards and after operation of 12 per cent inwards The difference between the MPs is significant P < 0 001

Conclusion

This investigation shows that in patients with cerebral palsy the hip joint migrating out wards can often be made to migrate inwards following an operation on the adductors pos sibly in combination with some other soft tissue procedures

Result of first operation on the adductors

Sharrard et al in 1975 analyzed the results which had been obtained in 154 hips by soft tissue procedures including adductor release and showed that operation on the adductors can often change a dysplastic hip into a normal hip while a subluxated *hip usually con tinues* to show some dysplastic features They therefore advised early operation and found that *in* 75 per cent of the cases one operative procedure on the adductors succeeded *in* ob taining or maintaining hip stability

Another thorough study of the effect of operation on the adductors was made by *Samilson et al* in 1967 However as their treatment included osteotomies on the femora the results cannot be compared with the results following soft tissue *procedures alone*

An attempt to confirm the conclusions reached by Sharrard et al would *thus* seem in dicated

Author s investigation

Table 6 shows that the primary median MP before and postoperative median MP *after the* first adductor operation are almost identical This must *signify that* the improvement gained as a result of the operation corresponds *numerically to the* increase in MP during the period of observation from the time the primary radiograph was taken until the operation took place This suggests that instead of *allowing* a period of observation to elapse there should have been surgical intervention *immediately*

In the adductor material on p 30 there are a *further* 18 hips for which only a pre operative radiograph was available prior to *the first* adductor *operation* and not a primary

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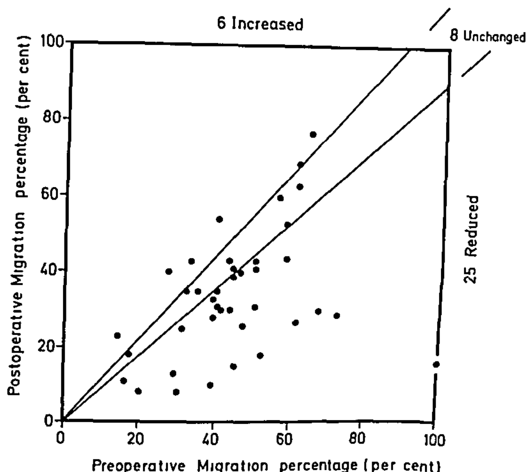


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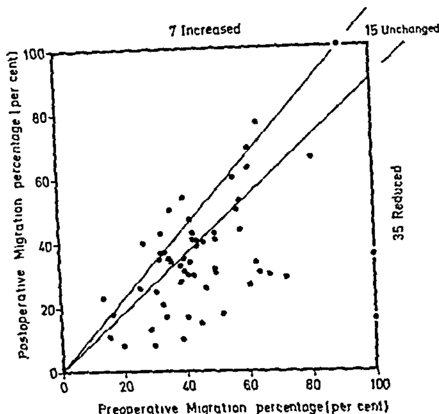


Figure 9
Migration of 57 cerebral palsy hips with and without preoperative observation after first operation on the adductors

wards in 69 per cent of the 39 hips before operation and that after operation 12 per cent of the 57 hips still migrated outwards This means that 57 per cent of the hips are seen to have improved or unchanged stability as a sequel to operation

Table 9 Spontaneous migration compared with postoperative migration

MIGRATION	n	NUMBER OF HIPS WITH INCREASED MIGRATION PERCENTAGE	UNCHANGED MIGRATION PERCENTAGE	REDUCED MIGRATION PERCENTAGE
Spontaneous	39	27 = 69%	12 = 31%	0
Postoperative	57	7 = 12%	15 = 26%	35 = 61%

Conclusion

This investigation confirms the finding of *Sharrard et al* (1975) that the first operation on spastic adductors results in the position of the femoral head in relation to the acetabulum being maintained or improved *in 57 per cent of* the cases (Sharrard et al achieved 75 per

radiograph as the patients underwent surgery without a period of observation as soon as it was established that at least one of the hips was subluxated *As the material of Sharrard et al* (1975) does not record preoperative migration of the hips the above hips can be included in the material compared with Sharrard s material provided their data do not deviate essentially from those of the 39 hips whose preoperative course was followed (raw data on p 82)

Table 7 Migration percentage before and after first operation on the adductors without preoperative observation

n = 18	MIGRATION PERCENTAGE per cent	
	PREOP	POSTOP
median	42	35
range	26-100	17-100

P < 0 001

Table 7 summarizes the measurements of the MPs of the 18 hips after the adductor operation The median value of the MP was 42 per cent preoperatively and 35 per cent postoperatively This difference is significant with P < 0 001 and corresponds to a migration of 7 per cent

A comparison with the preoperative *MP value in Table 6 shows that as the preoperative* MP is by chance nearly the same and as the postoperative MP does not differ significantly from that in Table 7 the results from the two Tables have been added in Table 8

Table 8 Migration percentage before and after first operation on the adductors with and without preoperative observation

n ≈ 57	MIGRATION PERCENTAGE per cent	
	PREOP	POSTOP
median	43	34
range	14 100	8-100

P < 0 001

The total of hips followed up after the first adductor operation is now 57 and Table 8 shows that they have been significantly improved (*P < 0 001)*

The result of the 57 adductor operations are visualized in Fig 9 As the diagram shows 35 hips were improved *15 were unchanged and* 7 had an increased MP in spite of the operation

On the assumption that the preoperative course for the patients who did not undergo observation before operation was the same as for those *patients who were observed it is possible* to construct Table 9 The table shows that there was a *spontaneous migration* out

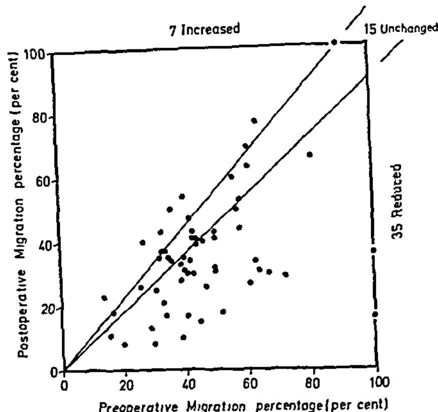


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cent) In addition the investigation confirms that if the decision as to treatment is to be based alone on an evaluation of the radiograph of the hips operation should be carried out as soon as a commencing subluxation has been identified since the first operation on the adductors cannot result in an optimal state of the hips if they are subluxated in advance and since the hips do not improve spontaneously

Result of all muscle operations

The account by Sharrard et al of operations to maintain hip stability includes femoral osteotomy in the final results From these results therefore it is still not possible to determine how far soft tissue procedures alone will maintain the stability of the hip

It is known that soft tissue operations for the sequelae of cerebral palsy have a high relapse frequency Thus even though as shown above a satisfactory result is obtained in 57 per cent of the hips after the first adductor operation it is nevertheless conceivable on a long term view that the desired results are not achieved with regard to preserving the stability of the hip

It was therefore found reasonable to examine the magnitude of the effect on the hip stability of soft tissue procedures alone both in relation to the first radiograph available of the patient s hips and in relation to the maximum hip migration percentage

Author's investigation

The »adductor material« on p 30 included 38 children who during the period 1st January 1969 to 1st July 1971 presented a definitely pathological hip joint These children underwent at least one adductor operation in one or both legs during the period in question These children were followed up measurements being made on subsequent radiographs Where osteotomies were performed on femora or pelvis measurements were made on the last radiograph prior to the bone surgery

Two children had to be omitted from the material one child because no radiographic examination of the hips had been made prior to the first adductor surgery while the other child died 7 months after operation without a control radiograph having been made (raw data on p 83 and 84)

Table 10 Result of all muscle operations *in relation to the primary and the maximal* migration percentage

n = 72	AGE years FINAL	OBSERVATION years	MIGRATION PERCENTAGE per cent PRIMARY	FINAL	MAXIMAL
median	10^{1}	6^{7}	31 5	26 5	44
range	5^{5}-23^{4}	1^{3}-18^{8}	0 100	7 100	15 100
			$P > 0 1$	$P < 0 001$	

Table 10 shows that the median value for the primary MP was 31 5 per cent After a median observation period of 6[7] years the MP was reduced to 26 5 per cent This difference is not significant $P > 0\ 1$

In relation to the maximum MP with a median value of 44 per cent which the hips have experienced in the course of the observation period the result of the operations has been to improve the hip stability to a median MP of 26 5 per cent This result is significant as $P < 0\ 001$

At the time of the final observation the patients were between 5[5] years and 23[4] years old with a median age of 10[1] years Nine of the patients were over the age of 12 years

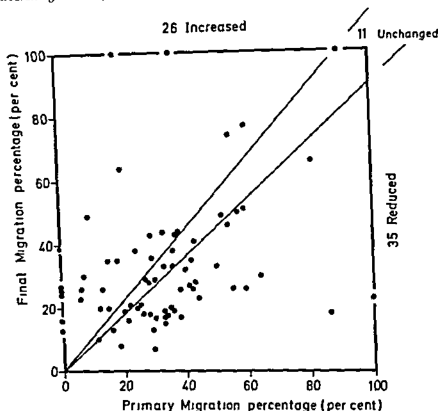


Figure 10
Migration after all muscle operations in relation to the primary migration percentage

Fig 10 visualizes the results of the operations in relation to the primary radiograph of the children taken before the first operation 35 hips were improved 11 hips remained unchanged and 26 hips increased their MP in spite of the operations Three hips dislocated

Fig 7 on p 30 shows the spontaneous migration of the cerebral palsy hips It is seen here that 27 out of 39 hips (= 69 per cent) migrated outwards Compared with Fig 10 it is seen that 26 out of 72 hips (= 36 per cent) migrated outwards after the muscle operations This means that on the long term view the muscle operations have had the effect of improving the stability in 69 per cent 36 per cent = 33 per cent of the hip joints

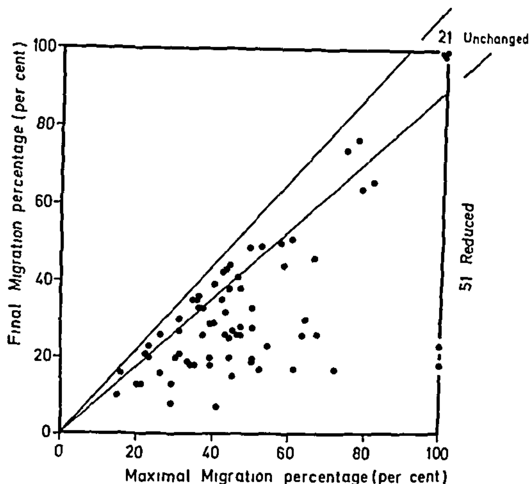


Figure 11
Migration after all muscle operations in relation to the maximal migration percentage

Fig 11 visualizes the results starting from the maximum MP experienced by the hips during the period of observation so that *none of the hips increased their MP and 51 (= 71 per cent) developed better stability Two of the hips which at one time were dislocated* migrated inwards to points 18 per cent and 23 per cent external to Perkins line

Table 11 Procedures in 36 children with cerebral palsy in the course of 87 hospitalizations during a period of observation with a median extent of 6⁷ years

Operations	n
Adductor release	91
Gracilis resection	83
Obturator anterior neurectomy	40
Hip flexor elongation	14
Hamstrings elongation	24
Abductor release	4
Yount s operation	3
Rectus elongation	5
Achilles tendon elongation	26

Table 11 reviews the number of individual interventions carried out in these 72 hip joints Only 63 of the hips underwent adductor surgery so that in the course of 6½ years an average of 1 4 operations were performed for each hip treated Several of the hips under went up to three adductor operations however as well as two resections of n obturatorius in order to retain stability The operations carried out during the course of 87 admissions to hospital

In 9 cases varus osteotomies of the femur were performed later and in two cases a pelvic osteotomy by the method of Chiari

Conclusion

In this investigation where 72 cerebral palsy hips were followed through several years (median period 6⁷ years) it was shown that by operations on the hip adductors including resection of the gracilis supplemented by anterior obturator neurectomy iliopsoas tendon elongation and hamstrings elongation stability has been maintained or improved in 33 per cent of the hips by comparison with the spontaneous migration from the acetabulum

By comparison with the maximum MP during the course of the period the operations have resulted in an improvement in stability in 71 per cent of the hips

General discussion

A satisfactory investigation depends just as much on an adequate patient material as on adequate methods of measurement

In this study it would have been an optimum condition if from a definite date the chil dren could have been followed by means of radiographs every 6 months for example until a number of the hips had subluxated and if surgical correction had been carried out only then This is not possible on ethical grounds

The study by *Sharrard et al* (1975) is based on those patients who had previously under gone treatment who attended for examination again i 1973 The radiographs made and the operations performed were analyzed retrospectively without any guarantee that patients whose hips had possibly dislocated in spite of the treatment had defaulted from control be cause others had formed an estimate that the children could not now be treated orthopaedi cally This may explain why Sharrard et al s material does not include children with dis located hips in the operated group

Contrary to this in the material of *Samilson et al* from 1967 there were 41 dislocated hips before operation and after treatment 26 of these were still dislocated In addition 7 out of 169 stable hips were dislocated in spite of operations including femoral osteotomies

In the present study where the primary aim was among other things to examine whether soft tissue surgery has an effect on the stability of the hip the starting material has been all those cases with subluxated hips which were operated on during a definite period These pa tients were then studied prospectively and retrospectively as a result of which it was pos sible in spite of lack of radiographs of the hips to collect a sufficiently extensive material which included among other things the preoperative course of the hip migration

In this material 3 of the hips became dislocated in spite of the adductor operation One of them was subsequently reduced by an osteotomy and in the other two cases no indications were found for suggesting further treatment

It might seem remarkable that as a result of the first adductor operation 57 per cent im proved in the first instance whereas the long term result often after several operations was about 33 per cent

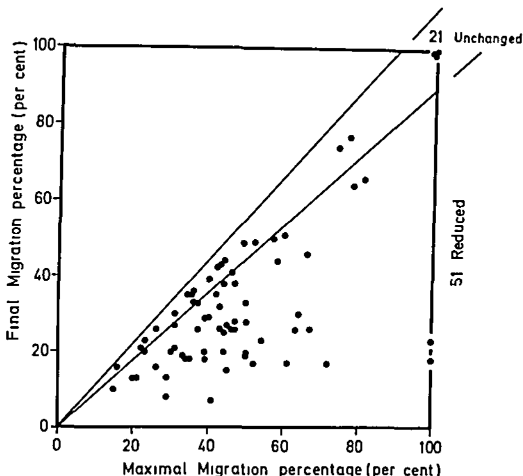


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Chapter V

Result of single operations

It was shown in the last chapter how the MP may decrease following adductor operation This however was often combined with other forms of soft tissue interventions It would therefore be desirable to analyze if possible the part played by such operations alone so as to obtain an impression of their contribution to the results

Migration index

In earlier analyses no allowance was made for the duration of the period of observation but it was merely noted whether the MP had increased in relation to operation If however it is a question of comparing the results of different operations by means of the magnitude of the MP it is necessary to allow for the time elapsed from the primary radiograph to the pre operative radiograph and again from the operation to the postoperative radiograph in order to obtain results which can be evaluated quantitatively

The concept *Migration Index (MI)* is therefore introduced giving the change in the MP in one year The MI has a negative sign if the femoral head migrates outwards in relation to Perkins line and a positive sign if it migrates inwards The difference between the post operative and preoperative MI then gives an indication of the *Result of the Treatment*

Example

The primary radiograph shows a MP of 20 per cent 18 months later the preoperative radiograph shows that the MP has become 30 per cent The MI is therefore $(20\ \ 30) \times \frac{12}{18} =\ \ 7$ per cent/year The MP five years postoperatively was measured as 40 per cent so that the MI now is $(30\ \ 40) \times \frac{12}{60} =\ \ 2$ per cent/year i e the hip is still migrating outwards after the operation but more slowly than before the operation The Result of the intervention is thus $2\ \ (\ 7) = 5$ per cent/year This signifies that the migration after treatment is 5 per cent less annually than it was before the operation or in other words each year the acetabulum covers 5 per cent more of the femoral head that it would have done without the operation

It is not possible to quote a MI of 7 per cent/year for the individual hip since the measure ment uncertainty is so great and in addition there is uncertainty as to whether the migra tion is linear However if the method is used for a larger number of hips before and after treatment the statistical analysis of the Results permits the uncertainty to be ignored

M gracilis resection

The effect of an organic or spastic contracture in the m gracilis is to reduce hip abduction when the knee is extended This is often one of the first contractures in children with cere bral palsy but as it is often combined with contractures in the other hip adductors or with contractures in the hamstrings it is quite unusual to lengthen the m gracilis as an isolated intervention

Assuming that it is a muscular imbalance which deforms the hip this may be explained by the elongated muscles being weakest immediately after an operation In the course of the child s continued growth the muscles regain some of their function when once more they become relatively shorter In those cases where the cerebral lesion and external circum stances in the form of effectiveness of training permit improved function of the antagonists to the muscles operated on may be achieved in the postoperative period If this improved function is not achieved after the first operation it seems as if the chance of this succeeding after the next operation is considerably less On the other hand if the hip deformation is due to a contracture the difference in operational results can be explained by the con *tracture recurring because of inadequate postoperative* prophylaxis

Although the aim of the present study has not been to elucidate the functional capacity of the children before and after the operations the question must be discussed here whether the result has been worth the efforts invested

If on Fig 11 a vertical line is drawn corresponding to the maximum MP of 50 per cent it is seen that of the total of 25 hips that had a greater MP than this before operation 20 have had a reduced MP after operation i e have obtained better stability contrary to what is known from experience that a »cerebral palsy« hip dislocates rapidly when only half of the femoral head is covered by the acetabulum which at that time is usually narrow and steep A possible explanation of the accelerated migration is the demonstration by *Fujiuara et al* in 1974 that there is greater electromyographic activity in more muscle groups around the hips in subluxation than in concentric hips or in dislocation

Experience as well as the reports in the literature show that dislocation in cerebral palsy patients is often accompanied by pain and in any case deterioration in general function to gether with nursing problems (*Weber* 1911 *Watson Jones* 1926 *Pollock & Sharrard* 1958 *Jones* 1962 *Ducharme* 1967 and *Samilson et al* 1972) In agreement with other authors (*Samilson et al* 1972 and *Sharrard et al* 1975) we therefore feel that these considerations justify the intervention independent of grade of intelligence and the ambulatory status

General conclusion

The preceding investigations have shown that in cerebral palsy the subluxated hip is most often acquired Such hips do not improve spontaneously Following an adductor operation possibly combined with other operations on muscles and tendons stability may be expected to be maintained or improved in 57 per cent of the hips

In 72 hips followed over a period of median 6^7 years stability was found to be retained or improved in about 33 per cent of the hips possibly after repeated operations

Among the 25 hips projecting more than 50 per cent beyond the roof of the acetabulum soft tissue procedures alone achieved a better stability in 80 per cent of the hips

The results indicate that the hips in this category of patients should receive operative treatment and the radiological results are better if treatment is instituted without allowing a period of observation to elapse once the head of the femur has *been observed to be sub* luxated At the same time the hips should be examined radiologically and the MP mea sured as soon as the diagnosis of cerebral palsy is made

Chapter V

Result of single operations

It was shown in the last chapter how the MP may decrease following adductor operation This however was often combined with other forms of soft tissue interventions It would therefore be desirable to analyze if possible the part played by such operations alone so as to obtain an impression of their contribution to the results

Migration index

In earlier analyses no allowance was made for the duration of the period of observation but it was merely noted whether the MP had increased in relation to operation If however it is a question of comparing the results of different operations by means of the magnitude of the MP it is necessary to allow for the time elapsed from the primary radiograph to the pre operative radiograph and again from the operation to the postoperative radiograph in order to obtain results which can be evaluated quantitatively

The concept *Migration Index (MI)* is therefore introduced giving the change in the MP in one year The MI has a negative sign if the femoral head migrates outwards in relation to Perkins line and a positive sign if it migrates inwards The difference between the post operative and preoperative MI then gives an indication of the *Result of the Treatment*

Example
The primary radiograph shows a MP of 20 per cent 18 months later the preoperative radiograph shows that the MP has become 30 per cent The MI is therefore (20 30) × $\frac{12}{18}$ = 7 per cent/year The MP fi e years postoperatively was measured as 40 per cent so that the MI now is (30 40) × $\frac{12}{40}$ = 2 per cent/year i e the hip is still migrating outwards after the operation but more slowly than before the operation The Result of the intervention is thus 2 (7) = 5 per cent/year This signifies that the migration after treatment is 5 per cent less annually than it was before the operation or in other words each year the acetabulum covers 5 per cent more of the femoral head that it would have done without the operation

It is not possible to quote a MI of 7 per cent/year for the individual hip since the measure ment uncertainty is so great and in addition there is uncertainty as to whether the migra tion is linear However if the method is used for a larger number of hips before and after treatment the statistical analysis of the Results permits the uncertainty to be ignored

M gracilis resection

The effect of an organic or spastic contracture in the m gracilis is to reduce hip abduction when the knee is extended This is often one of the first contractures in children with cere bral palsy but as it is often combined with contractures in the other hip adductors or with contractures in the hamstrings it is quite unusual to lengthen the m gracilis as an isolated intervention

Before 1969 the operation was usually carried out medially on the femur just proximal to the knee by resecting 1 cm of the tendon and the peritendinum After 1969 if operation was combined with an adductor operation the procedure included myotomy of the m gracilis at its origin on the ramus inferior ossis pubis The effect of the two operation variations must be the same

Author's investigation

A total of about 1700 children with cerebral palsy received treatment in the Outpatients Department for Handicapped Children the Rigshospital during the period 1950 to 1976 The case records were reviewed to extract all those patients satisfying the condition that not only should there be a preoperative radiograph of the hips but also a primary and a postoperative radiograph made at least 5 months before and after operation *respectively A total of* 10 patients were found who satisfied these requirements having undergone a total of 19 single gracilis resections The MP was determined and recorded on curves (raw data p 85)

Table 12 Result of m gracilis recection in 19 hip joints

n = 19	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^1	1^6	1^4	15	21	22	2
range	2^7-7^6	0^5-2	0^5-4^5	0-38	3-47	5-52	-14-31

P > 0 1

Table 12 summarizes the measurements and shows that the overall median Result of the m gracilis resections was 2 per cent/year evaluated from the raw data of the MIs before and after operation The Result is not significant as *P > 0 1*

The outwards migration before operation changed from a median value of 15 per cent to a median value of 21 per cent in the course of 1^6 years and then ceased the MP 1^4 years after the operation being 22 per cent

N obturatorius resection

The anterior branch of the nerve supplies *mainly the mm adductor longus and brevis and* the m gracilis with motor branches but because of accessory branches and communication with other nerve branches the area of innervation is not stable This is now the last neurectomy still employed since the days when it was common to employ a variety of neurectomies (*Vulpius & Stoffel* 1913)

Because of risk of paralysis of the adductors *and in consequence contracture in the abductors* (*Silver et al* 1966) only a single total obturator neurectomy has been performed in Copenhagen *Hagberg et al* in 1964 analyzed the results following total obturator neurectomy in 41 children with cerebral palsy but they did not mention the possible effect on the stability of the hip

Anterior neurectomy is usually *performed in connection* with adductor tenotomy 1 cm of

the anterior branch of the obturator nerve being resected Care is taken that this is the nerve branch either by electrical stimulation or merely by pinching the nerve which results in a brief contraction of the associated muscles Microscopic identification of the nerve was not ensured in all operations The anterior branch of the nerve has a tendency to partial re generation while becoming thicker at the same time Microscopy shows degenerative changes with fibrous splitting and the formation of neuromata Among the 38 children with subluxation of the hip mentioned on p 30 there are 4 cases where the nerve was resected twice

Author's investigation

The material from the Rigshospital was found to include 6 single neurectomies and 4 operations which were combined with m gracilis resection As the Result following gracilis resection alone is known from previous investigations these 4 cases were included (raw data on p 85)

Table 13 Result of anterior obturator neurectomy in 10 hip joints

n = 10	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	8^{2}	1^{6}	2	17 5	21 5	22	4
range	2^{10} 11^{6}	0^{11}–6^{9}	1^{1} 2^{9}	0 40	8-41	10-43	-1-6

P = 0 011

Table 13 summarizes the measurements and shows that the overall Result of the 10 opera tions including 4 gracilis resections has been 4 *per cent/year* After operation the hips have retained the preoperative stability in spite of the migration that took place primarily The difference between preoperative and postoperative MI is significant P = 0 011

Elongation of hip flexors

These operations were all performed by a procedure described by *Anthonsen* in 1966 and later illustrated by *Baumann* in 1970 The procedure includes an open elongation of the psoas tendon and a distal resection of the iliacus muscle The rectus tendons are elongated and the origin of the sartorius muscle transferred to the anterior inferior iliac spine The pa tient was kept in abduction splinting (*Anthonsen & Reimers* 1970) for 3 weeks and an in tensive postoperative training program initiated which included active rehabilitation of the abductors and stretching of the remaining hip flexion contracture The follow up of 58 pa tients in 1966 by *Anthonsen* showed that the contracture had disappeared wholly or partly in all

Author s investigation

The material from the Rigshospital was found to include 11 children who satisfied the re

Before 1969 the operation was usually carried out medially on the femur just proximal to the knee by resecting 1 cm of the tendon and the peritendinum After 1969 if operation was combined with an adductor operation the procedure included myotomy of the m gracilis at its origin on the ramus inferior ossis pubis The effect of the two operation variations must be the same

Author's investigation

A total of about 1700 children with cerebral palsy received treatment *in the Outpatients De partment* for Handicapped Children the Rigshospital during the period 1950 to 1976 The case records were reviewed to extract all those patients satisfying the condition that not only should there be a preoperative radiograph of the hips but also a primary and a postoperative radiograph made at least 5 months before and after operation respectively A total of 10 patients were found who satisfied these requirements having undergone a total of 19 single gracilis resections The MP was determined and recorded on curves (raw data p 85)

Table 12 Result of m gracilis recection in 19 hip joints

n = 19	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	*PREOP*	*POSTOP*	*PRIM*	*PREOP*	*POSTOP*	
median	4^1	1^6	1^4	15	21	22	2
range	2^7-7^6	0^5-2	0^5-4^5	0-38	3-47	5-52	-14-31

P > 0 1

Table 12 summarizes the measurements and shows that the *overall* median Result of the m gracilis resections was 2 per cent/year evaluated from the raw data of the MIs before and after operation The Result is not significant as P > 0 1

The outwards migration before operation changed from a median value of 15 per cent to a median value of 21 per cent in the course of 1^6 years and then ceased the MP 1^4 years after the operation being 22 per cent

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The anterior branch of the nerve supplies mainly the mm adductor longus and brevis and the m gracilis with motor branches but because of accessory branches and communication with other nerve branches the area of innervation is not stable This is now the last neurec tomy still employed since the days when it was common to employ a variety of neurectomies (*Vulpius & Stoffel* 1913)

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Anterior neurectomy is usually performed in connection with adductor tenotomy 1 cm of

Table 15 summarizes the measurements and shows that the overall Result of the 43 operations including 9 gracilis resections was a median of 1 per cent/year The difference between MIs of the raw data before and after the treatment is significant at the 1 per cent level $P < 0.01$

Operations with and without m gracilis resection

The preceding analyses of obturatorius neurectomy and elongation of the hip flexors and hamstrings have shown only a doubtful and slight effect on the migration of the hips These Results could be due to the gracilis tendon often being resected at the same time For this reason an analysis was made of the part played by single operations in the total of Results

Author's investigation

The measurements were grouped into two classes depending on whether the gracilis muscle had been resected or not (Raw data on p 85 86 and 87)

Table 16 Results of anterior obturator neurectomy elongation of the hip flexors and proximal elongation of the hamstrings with and without m gracilis resection

GRACILIS RESECTION	n		AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULTS per cent/year	P
WITH	23	median	7^{9}	18	1	> 0 1
		range	5^{4} 12^{10}	5 31	-2-11	
WITHOUT	52	median	11	17	1	
		range	2^{10} 15^{4}	0 41	-7 12	

Table 16 shows the most important measurements and it is seen that of the total of 75 operations the same positive Result was obtained in both groups independent of whether a gracilis resection was performed at the same time or not

Elongation of tendo Achilles

As a further control of the Results following operations on the muscles around the hip joint the Result was tabulated for an operation which is presumably quite indifferent with respect to the hip joint

The elongation of the tendo Achilles was carried out in all cases via a posterior incision The tendon was elongated by a horizontal Z shaped incision distally on the leg A leg cast with the foot in neutral position was then applied for 3 weeks and a walking cast for a further 3 weeks

quirements laid down for radiological observation before and after operation with a total of 22 elongations of the hip flexors 10 of the operations being combined with gracilis resections (raw data on p 86)

Table 14 Result of elongation of the hip flexors in 22 hip joints

n = 22	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	9^{9}	2^{6}	3	14	15 5	13 5	0
range	6^{2}-14^{6}	0^{7}-7^{6}	0^{8}-5^{11}	0-35	0-30	1-28	-7-11

$P > 0\ 1$

Table 14 summarizes the measurements and shows that the overall Result of the 22 operations including the 10 gracilis resections has been a median value of 0 per cent/year The difference between preoperative and postoperative MIs of the raw data is not significant $P > 0\ 1$

Proximal elongation of the hamstrings

These operations were all performed as an elongation of the proximal origin of the muscles The tendons are released from the musculature which is transected proximally and the tendons cut intramuscularly about 7 cm distal to the ischial tuberosity Suture of the muscle bellies to the proximal tendon stumps gives a controlled elongation The result of these operations was summarized by *Reimers* (1974)

Author's investigation

The material consists of all those patients with cerebral palsy who underwent proximal elongation of the hamstrings at the Orthopaedic Hospital Copenhagen from 1969 to 1971

The choice of patients was such that adductor operations had not been performed at the same time and that radiographs of the hip joint were available so that the course of the hip migration could be calculated for at least 6 months before and after the operation This selection reduced the material to 23 patients with a total of 43 operations including 9 gracilis resections (raw data on p 87)

Table 15 Result of proximal elongation of the hamstrings in 43 hip joints

n = 43	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	10^{11}	2	2^{2}	17	18	17	1
range	4^{5}-15^{4}	0^{6}-6^{4}	0^{11}-4^{8}	0 33	4 33	7 34	5 12

$P < 0\ 01$

Discussion

After the positive results of the adductor operations on p 33 it might have been expected that the investigation would show a definite positive effect from the obturator neurectomies as this should produce a weakening of the adductors In spite of the small number of hips studied the operation appears to have a significant effect of in median value 4 per cent/year

The lack of effect of the elongation of all the hip flexors was to be expected after the clinical experience with the hip joint in cerebral palsy and myelomeningocele The number of operations is not high but even an analysis of a larger number would hardly bring the Results obtained up to the level of those in the analysis of adductor operations in Chapter IV

A Result equal to 1 per cent/year after proximal elongation of the hamstrings is small even though there is a significant difference between the preoperative and postoperative values of the MIs However the median value for age is almost 11 years and as will be shown later the Result following adductor operations depends on age and is greatest in children below the age of 4 years The same must hold for hamstring operations

Michelsson & Langenskiold s theory from 1972 which they supported by animal experiments that the hamstrings may provoke dislocation of the hip in infants in a frank breech presentation with extended knees and flexed hips is not contradicted by the slight improvement in the stability of the hips after elongation of the hamstrings as these children were all over 4 years of age and further it is only during treatment with exercises that the knees are extended while there is simultaneously flexion at the hips

If the explanation of the positive Result after operation on the hamstrings was that the children walked more and better after the operation it would be anticipated that elongation of the tendo Achilles had the same favourable effect on the hip joints On the contrary a significantly greater outwards migration of the femoral head was found after the operation than before The negative Result however is not of such a magnitude as to contraindicate elongation of the tendo Achilles The explanation may be that although the children walk more and better after the operation and thereby strengthen the muscles that maintain the standing position it is conceivable that they strengthen those muscles most that are already the best functioning (*Plum* 1975) The effect is accentuation of the existing muscle imbalance responsible for migration If this explanation is correct the analysis confirms the experience that it is not the poor extent of the ambulation that is significant for the development of the hip dislocation but the poor quality The positive Result after elongation of the hamstrings is therefore hardly due to the increase in ambulatory function

In single m gracilis resection the Result found was 2 per cent/year When the operation was combined with another type of intervention in the form of obturator neurectomy elongation of the hip flexors or hamstrings the Result was in median only 1 per cent/year The difference is not significant but if it were real it could be explained by the higher age for the combined operations than for the single m gracilis operations

The lack of any Result from the operations without m gracilis resection at the same time in the case of children with a median age of 11 years suggests that the same operations at the age of 4 years will at most give a Result equal to that of gracilis resection at the same age

Author's investigation

The material originates from the Rigshospital s material of 1700 children among whom a total of 21 single elongations were found which satisfied the conditions for preoperative and postoperative observation of the hip joints Elongation of the tendo Achilles is a very com monly employed operation but it has often been carried out at such an early age that no preoperative radiographs are available (raw data on p 88)

Table 17 Result of tendo Achilles elongation in 21 hip joints

n = 21	AGE years OP	OBSERVATION years PREOP	POSTOP	MIGRATION PERCENTAGE per cent PRIM	PREOP	POSTOP	RESULT per cent/year
median	4^{7}	1^{6}	1^{7}	14	15	16	-4
range	2^{7}-7^{4}	0^{7}-1^{9}	0^{10}-1^{11}	0-33	0-32	2-39	-21-6

$P < 0\ 02$

Table 17 summarizes the observations and the Result is seen to be -4 per cent/year Examining the median values of the MP before and after operation the migration rate would appear to have been constant from 14 per cent to 15 per cent before operation and from 15 per cent to 16 per cent after operation However the median value of the Results on the basis of the individual operations is negative and the difference in MI from before to after operation is significant at the 2 per cent level as $P < 0\ 02$

Table 18 Review of the median values of the preoperative migration percentages and the Results in the single soft tissue operations

OPERATIONS	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULTS per cent/year	P
OBTURATOR NEURECTOMY	10	8	21 5	4	= 0 011
HIPFLEXORS	22	10	15 5	0	> 0 1
HAMSTRINGS	43	11	18	1	< 0 01
ABOVE OP WITH GRACILIS	23	8	18	1	> 0 1
ABOVE OP WITHOUT GRACILIS	52	11	17	1	
SINGLE GRACILIS	19	4	21	2	> 0 1
TENDO ACHILLES	21	5	15	4	< 0 02

Chapter VI

Analysis of adductor operations

It was demonstrated in Chapter IV that by adductor myotenotomy possibly in combination with other soft tissue operations the MP in the subluxated cerebral palsy hip could be in fluenced to a considerable degree

Chapter V examined the Results of m gracilis resection obturator neurectomy elonga tion of the hip flexors or elongation of the hamstrings as single procedures and it was shown that at most these procedures influenced the migration slightly in the same positive direc tion as the combined adductor operations

Adductor intervention therefore appears to be the factor mainly responsible for the major results in the treatment and prophylaxis of the migrating hip

Having thus evaluated the Results following the individual soft tissue operations the ad ductor operations can now be analyzed more closely with regard of the influence of various factors on the Results

Author's investigation

The basis for the analysis of the adductor operations is the same patient material which was used to determine the effect and the result of the operations on the cerebral palsy hips in Chapter II In this and the following investigations the earliest available radiograph of the hips was not always the one used as the aim has been to have the preoperative observation and postoperative observation periods as equal as possible For the purpose of the analysis only hip joints were used where there has been a preoperative observation period with radiographs of at least 3 months (Raw data p 89 and 90)

The first adductor operation

Table 19 Result of the first adductor operation

n = 39	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^3	0^9	1^5	33	43	33	15
range	1^3 18^9	0^3 7^3	0^8 2^9	0 86	14 100	8 69	31-100

P < 0 001

Table 19 summarizes the measurements showing that the Result of the first adductor operation was a median value of 15 per cent/year The improvement is significant P < 0 001

Before the operations the hips migrated outwards in median 7 per cent each year corre sponding to a median MI of 7 per cent/year this being that value found on calculating from the MIs for the individual hips

Conclusion

The investigation of single operations in the form of resection of m gracilis elongation of the hip flexors including the iliopsoas rectus and sartorius as well as proximal elongation of the hamstrings has shown that elongation and weakening of these muscle groups gives a change in the yearly migration of at most 2 per cent by a median age of 4 years Compared to the spontaneous preoperative migration of about 10 per cent yearly found on examination of subluxated »cerebral palsy« hips on p 31 in Chapter IV the muscle groups in question can at most be of minor importance for the hip migration

The positive Result of resection of the anterior branch of the obturator nerve supports the finding in Chapter IV that the function of the adductor muscles are of great importance for the migration of the hip joint

The negative Result following elongation of the tendo Achilles supports the theory of muscle imbalance as the cause of the hip migration since a quantitative increase in ambulation may accentuate the already existing imbalance if the use of the muscles around the hip is not improved qualitatively at the same time

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P < 0 001

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Before the operations the hips migrated outwards in median 7 per cent each year corre sponding to a median MI of 7 per cent/year this being that value found on calculating from the MIs for the individual hips

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The investigation of single operations in the form of resection of m gracilis elongation of the hip flexors including the iliopsoas rectus and sartorius as well as proximal elongation of the hamstrings has shown that elongation and weakening of these muscle groups gives a change in the yearly migration of at most 2 per cent by a median age of 4 years Compared to the spontaneous preoperative migration of about 10 per cent yearly found on examination of subluxated »cerebral palsy« hips on p 31 in Chapter IV the muscle groups in question can at most be of minor importance for the hip migration

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The negative Result following elongation of the tendo Achilles supports the theory of muscle imbalance as the cause of the hip migration since a quantitative increase in ambulation may accentuate the already existing imbalance if the use of the muscles around the hip is not improved qualitatively at the same time

Table 22 Unilateral adductor operation effect on the ipsilateral hip

n = 21	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	5^{1}	0^{9}	1^{4}	38	45	30	11
range	1^{1} 12^{11}	0^{3} 3^{6}	0^{7}-2^{9}	18 86	29-100	10 61	5-100

P < 0 001

Table 22 shows that the Result of the operations has been a median value of 11 per cent/year The difference between the MIs before and after operation is significant P < 0 001

Table 23 Unilateral adductor operation effect on the contralateral hip

n = 21	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	5^{1}	0^{9}	1^{4}	19	21	29	-4
range	1^{1} 12^{11}	0^{3} 3^{6}	0^{7} 2^{9}	0 50	6 36	5 59	-34 22

P > 0 1

Table 23 summarizes the measurements of the hip joints on the side contralateral to the uni lateral adductor operations During the period before the operation the median values showed a slight increasing MP as in most cases an earlier adductor operation had been per formed also on this side

The effect of the contralateral operation showed a median value of 4 per cent/year There is no significant difference between preoperative and postoperative MIs P > 0 1 On the other hand there is a significant difference between the Result of the operation on the two sides P < 0 01

Significance of the neuromotor lesion

Table 24 Result of adductor operation according to the extent of the neuromotor lesion

DIAGNOSIS	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
Para diplegia	28	5^{7}	40	9	= 0 6
Tetraplegia	33	4^{2}	45	11	

The secondary adductor operations

Table 20 Result of the secondary adductor operations

n = 22	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			RESULT per cent/year
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	
median	4^{11}	1^{2}	1^{8}	41 5	43	29 5	6 5
range	3^{3}-12^{7}	0^{4}-3^{11}	0^{7}-2^{8}	4-63	9-63	18-56	-51-64

0 02 < P < 0 05

Table 20 shows the Results after one or more reoperations The median Result was 6 5 per cent/year which improvement was significant 0 02 < P < 0 05

Before the secondary operation the femoral head was stationary in relation to the aceta bulum as the median value of the preoperative MI was 0 per cent/year when calculated from the MIs for the individual hips

Comparison of the first and the secondary adductor operations

Table 21 Comparison of the Results of first and secondary adductor operations

ADDUCTOR OPERATIONS	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
FIRST	39	4^{3}	43	15	*< 0 001*
SECONDARY	22	4^{11}	43	6 5	

Table 21 compares the most important data of the first and the secondary adductor opera tions

Age and preoperative MP are of the same magnitude but nevertheless the Result of re operation is only less than half of that obtained from the first operation The difference be tween the Results *of the operations is significant* P < 0 001

Unilateral adductor operation

Of the total material of adductor operations with a known preoperative and postoperative course those 21 operations have been selected which were carried out on the one side only The Result of operation was then calculated both for the ipsilateral hip (raw data on p 90) and for the contralateral hip (raw *data on p* 91)

tion that the result of soft tissue intervention around the hip joint is better in children under the age of 4 years (Raw data on p 89 and 90)

Table 27 Result of adductor operation according to age

AGE	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
≤ 4 years	23	2^{11}	43	16	= 0 012
> 4 years	38	6^{1}	40	8	

The Table shows that the Result following adductor operation was greater in children under the age of 4 years and the difference is significant P = 0 012 In both groups the preoperative MP showed a median value of more than 40 per cent

Significance of the preoperative migration percentage

The material was then grouped according to the magnitude of the preoperative MP as this likewise appears to have some significance for the Result (Raw data on p 89 and 90)

Table 28 Result of adductor operation according to preoperative migration percentage

PREOPERATIVE MIGRATION PERCENTAGE	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
≤ 40 per cent	29	5^{11}	32	7	< 0 01
> 40 per cent	32	4^{1}	50	13	

The Table shows that there is a significant difference in the Results P < 0 01 the Result being better when the MP was more than 40 per cent Note that the median age is more than 4 years of age in each case

Significance of age and preoperative migration percentage in combination

The two preceding analyses show that both a low age and a high preoperative MP give best median Results The material has therefore been divided into four groups in order to compare the pairwise effect of the factors

The total adductor material was grouped according to the extent of the sequelae of the cerebral palsy Para diplegics are spastic in both legs and at most slightly in the arms Tetraplegics have also a function impeding spasticity in the arms (Raw data on p 89 and 90)

Table 24 summarizes the essential data There is no significant difference between the Results in the two groups P = 0 6

Significance of the intelligence

The adductor material is grouped according to the IQ A low IQ designates those children who at the time of operation were already under the Care of the Danish National Service for the Mentally Retarded or were expected to come under this The upper limit for low IQ has been put at about 75

Table 25 Result of adductor operation according to the relative IQ

IQ	n	AGE year OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
LOW IQ	35	4^{7}	44	9	= 0 3
NORMAL IQ	26	4^{7}	40	10 5	

The Table summarizes the most important data There is no significant difference between the Results of the operations in the two groups P = 0 3

Significance of sex

The material is grouped according to boys and girls (Raw data on p 89 and 90)

Table 26 Result of adductor operation according to sex

SEX	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
GIRLS	28	5^{4}	42	9	= 0 8
BOYS	33	4^{3}	41	11	

The Table shows that the difference between the Results in the two groups is not significant P = 0 8

Significance of age

The material is grouped according to age as there were indications earlier in the investiga

ion that the result of soft tissue intervention around the hip joint is better in children under the age of 4 years (Raw data on p 89 and 90)

Table 27 Result of adductor operation according to age

AGE	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
≤ 4 years	23	2^{11}	43	16	= 0 012
> 4 years	38	6^{1}	40	8	

The Table shows that the Result following adductor operation was greater in children under the age of 4 years and the difference is significant P = 0 012 In both groups the preoperative MP showed a median value of more than 40 per cent

Significance of the preoperative migration percentage

The material was then grouped according to the magnitude of the preoperative MP as this likewise appears to have some significance for the Result (Raw data on p 89 and 90)

Table 28 Result of adductor operation according to preoperative migration percentage

PREOPERATIVE MIGRATION PERCENTAGE	n	AGE years OP	MIGRATION PERCENTAGE per cent PREOP	RESULT per cent/year	P
≤ 40 per cent	29	5^{11}	32	7	< 0 01
> 40 per cent	32	4^{2}	50	13	

The Table shows that there is a significant difference in the Results P < 0 01 the Result being better when the MP was more than 40 per cent Note that the median age is more than 4 years of age in each case

Significance of age and preoperative migration percentage in combination

The two preceding analyses show that both a low age and a high preoperative MP give best median Results The material has therefore been divided into four groups in order to compare the pairwise effect of the factors

Table 29 Result of adductor operation according to age and preoperative migration percentage

AGE AT OP	MIGRATION PERCENTAGE PREOP	
	≤ 40 per cent	> 40 per cent
≤ 4 years	n = 9 10 per cent/year	n = 14 21 per cent/year
> 4 years	n = 20 5 5 per cent/year	n = 18 10 per cent/year

Table 29 *shows the Result of the adductor operations grouped according to age and pre* operative MP There is a significant difference between the Result for preoperative MP less than and more than 40 per cent and the child under 4 years of age as well as between the Results for age less than and more than 4 years of age and the MP more than 40 per cent

The *best* Result was found when the child was under the age of 4 years and the hip had migrated at least 40 per cent Conversely the Result was least good when the patient was over 4 years of age and the hip had migrated less than 40 per cent

Discussion

The analysis of the first adductor operation shows that the Result was 15 per cent/year This *confirms the result of the* pilot investigation in Chapter IV

The Result of the adductor operations is of quite another order of magnitude to that of the other operations except anterior obturator neurectomy examined in Chapter V In *what follows therefore no account has been taken of the* accompanying soft tissue operations

An analysis of the individual measuring data shows that the median value of the pre operative spontaneous MI was 7 per cent/year while the pilot investigation showed a migration about 10 per cent each year

An examination of the secondary adductor operations shows that the median Result was 6 5 per cent/year This means that since after the earlier operations on the adductors no certain migration was found the secondary operations must have resulted in an improvement

The finding that the Result of the secondary operations is less than those of the first operations suggests that what is of greatest significance for the stability of the hips is an im balance between hip abductors and adductors If a better function of the hip abductors was not achieved following the first operation this possibility is no doubt present following the secondary operations but to a significantly smaller degree than after the first operation

Samilson et al (1967) warned against unilateral adductor myotomies in cerebral palsy be cause of the risk of abduction *deformity* of the operated hip and adduction contracture and

subluxation of the unoperated hip *Baacke & Tonnis* (1974) and *Bjerkreim* (1974b) showed how a hip which is loaded in abduction results in secondary dysplasia and possibly osteo arthrosis in the contralateral hip which becomes adducted In view of these findings the unilateral adductor operations have been analyzed using both the first operation and se condary operations with a known preoperative and postoperative course

Comparing the effect on the hips operated on unilaterally in Table 22 with the effect on the contralateral unoperated hips in Table 23 it is seen that in spite of both first operation and secondary operations the Result in these unilateral operations was of the same magni tude as the Result in the case of the first bilateral operation but it seems that the operation exerting a negative influence on the unoperated hip the non significant median value of the Results for these being 4 per cent/year

Anyone with experience in such operations however knows of cases where a unilateral adductor tenomyotomy involves a risk of dislocation in the contralateral hip This was the case with patient No 25 for example with spastic tetraplegia and unilateral dislocation of the hip After the hip was reduced by means of adductor tenomyotomy the outwards migration of the contralateral hip was accelerated The control was stopped and three years after the first operation this hip was found dislocated (This was after the end of the period of observation) Among other forms of intervention an osteotomy of the femur was performed to reduce the hip

If the hypothesis is correct that the hip is affected by the function of the surrounding muscu lature no difference should be anticipated in the radiological Results of operation on account of differences in the type of spasticity diagnosed IQ or sex provided the preopera tive MP and age are the same Even though these prerequisites could not be fulfilled com pletely the investigation shows that in fact no differences in Results were found as postu lated

Previously attempts to treat deformities in the hips in cerebral palsy were advised against if the patient was neurologically and intellectually immature *Samilson et al* showed in 1972 that it can pay to provide treatment for the hip in this group of patients as well with a view to preventing subsequent complications craving nursing care such as pain scoliosis fractures and decubitus The present study confirms that the Result of adductor operations measured by the stability of the hip before and after operation is independent of the extent of the neurological lesions and of the IQ It has been shown in a corresponding manner (*Rei mers* 1974) that the result of operation for contracture of the hamstrings in children with cerebral palsy is also independent of the IQ

The analysis of age and preoperative MP shows that both these factors are of significance for the Result of the adductor operations without it being possible to decide whether an age less than 4 years or a preoperative MP of more than 40 per cent is the more important factor

Samilson et al in 1967 found that the best hip stability after soft tissue operations was ob tained in children under 12 years of age The present investigation does not exclude the pos sibility that in isolated cases good results can also be obtained in older patients

Example

Patient No 20 a boy with spastic diplegia and mental retardation Examination at the age of 17 years showed no ambulatory function but good control of the head The sitting position was poor because of adduction of the right hip and a considerable clinical scoliosis There was contracture of the hip ad ductors and flexors as well as of the hamstrings with organic limitation of extension in the knees A rad ograph of the hip joints showed a MP of 55 per cent in the right hip and of 24 per cent in the left hip There was no pain and as the patient was 17 years of age it was not considered that his condition

would become exacerbated so operation was abstained from

A year later there was pain in the right hip the scoliosis had progressed the sitting position was poorer and nursing care was more difficult because of a combined hip abduction of 25° With extended hips and knees the legs could not be abducted at all

Almost 5 years after bilateral adductor tenomyotomy and resection of the m gracilis and psoas tendons almost symmetrical hip joints were found The sitting position was improved The scoliosis was only moderate and did not impede function The general condition of the patient was more satisfactory and it was easier to provide nursing care Fig 12 shows the Result of the operation on the migration of the hips

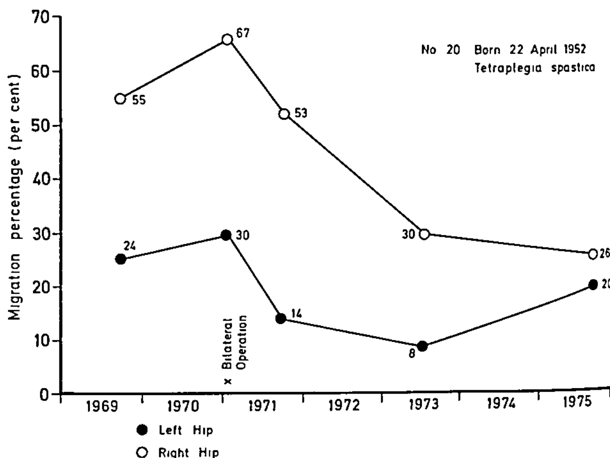


Figure 12
Visualization of the result of adductor operation at the age of 18 years

The great significance of age and preoperative MP for the outcome of adductor operations makes it necessary to revise our evaluation of the Results following gracilis and obturator neurectomy as well as elongation of the hip flexors or the hamstrings as the influence of the two factors mentioned on these operations has presumably the same significance as in the case of the adductor operations

Table 18 shows that the Result of the anterior obturator neurectomy alone was 4 per cent/year with a median age of 8 years and a preoperative MP of 21 5 per cent Comparing this Result with that in Table 29 it is seen that the Result of adductor operation in children more than 4 years of age (median 6^{10} years) and with a preoperative MP of less than or equal to 40 per cent (median 35 per cent) was of the same order of magnitude namely 5 5 per cent/year This suggests that the Result of the obturator neurectomy is a real one as might have been expected

The Result of the elongation of the hamstrings was only 1 per cent/year with a high age and low preoperative MP so that further investigations are necessary for example following operations preferably on younger patients before it can be established that the hamstrings are of significance for the quality of the hip joint

Table 18 shows that the Result of the gracilis resection alone was 2 per cent/year with a median age of 4 years and a preoperative MP of 21 per cent The Result of the resections is not statistically significant This problem however might be clarified in the following manner

The gracilis muscle functions as a hip adductor when the knee is held in the extended position and in the standing position it thus contributes to crossing the legs In the sitting position the knee is bent and as a result the m gracilis is relaxed and can therefore not affect the hip directly If at the same time there are contractures in the m gracilis and in the tensor fascia lata or in the other hip abductors the child will often lie spontaneously in the frog position but this position corresponds to the Lorenz I position which was employed before Salter s human position (*Salter et al* 1969) to improve the position of the femoral head in the acetabulum in congenital dislocation of the hip From static and dynamic considerations therefore the m gracilis would not be expected to influence the hip unfavourably when the child is sitting or lying with bent knees However the Result of these operations which in spite of all was positive if not significant can also be explained by the fact that after the operation the hip joints have been kept in abduction for 3 weeks often followed by an abduction night splintage with the result that the other hip adductors have come under tension and perhaps elongated as a result

To investigate further the significance of the m gracilis for the hip joint one could examine whether there is a relationship between the abduction of the hip with the m gracilis stretched and relaxed and the simultaneous MP of the same hip

Conclusion

The analysis of adductor operations in cerebral palsy hips has shown a significant improvement in the relation to the femoral head to the acetabulum

The first adductor operation gives a significantly better Result than the secondary interventions Measured by the MIs the Result of the reoperations is only less than half of the first operation in spite of equality of age and preoperative MP

On analyzing all adductor operations with a known preoperative and postoperative course of hip migration a significant improvement is found after unilateral operations As far as the median value is concerned the contralateral non operated side shows a non significant reverse effect about one third of that Result obtained on *the ipsilateral side*

The extent of the cerebral lesion expressed by the diagnosis para diplegia or tetraplegia is not found to have any essential or significant effect This suggest that the hip joint is only influenced by the function of the peripheral surrounding structures and is unaffected by the cerebral neurolesion

Differences in IQ and sex have likewise no significance for the Result

On the other hand there is a significantly greater improvement in the stability of the hip in children under 4 years of age and in hips with a preoperative MP of more than 40 per cent without it being possible to find any significant difference in the weight of these two factors

As was concluded in Chapter IV however one should not wait until the MP is over 40 per cent to get a greater improvement Provided the hip status alone indicates operation treatment should be instituted as soon as it can be observed that the hip has migrated outwards

if the best radiological Result is to be obtained on the long term view This requires evalua tion of the stability of the hip on a radiograph as soon as the diagnosis of cerebral palsy is suspected

Comparing the Results of anterior obturator neurectomy with the adductor operations with nearly the same age and preoperative MP it is clear that the Results are of the same magnitude

Elongation of the hip flexors did not provide a better stability of the hip joints on the other hand it is not possible to exclude that operations on the hamstrings or m gracilis might have an importance for the migration of the hip joint

Chapter VII

Relation between migration percentage and abduction of the hip

Among other results in the previous pages it was shown that a femoral head which migrates outwards spontaneously can after elongation and at the same time weakening of the adductor muscles be brought to migrate inwards under the acetabulum in relation to Perkins line This result of the operation must be due to a termination of the influence of the deforming force The deforming force may therefore be the contracture which was removed by the operation on the adductors or it may lie in a too powerful functioning of the adductor muscles in relation to the antagonists the hip abductors

It should be possible to determine which factor is the more important by examining the correlation between the hip abduction and the MP A high correlation must signify that abduction is of great importance for the stability of the hip and conversely a low correlation that abduction is of slight significance

Adductor operations are often combined with a gracilis resection so in order to distinguish if possible between the isolated gracilis effect on the stability of the hip and the effect of the other adductors the investigation should be done with the legs both flexed and extended

Author's investigation

The material consists of 95 children with cerebral palsy examined at the Rigshospital and in the Outpatient Clinics of Ebberodgård and the Children s Hospital Vangede (Subnormality Institutes) All the children had undergone the first adductor operation after 1st January 1969 at the Orthopaedic Hospital Copenhagen or after the 1st April 1973 at Orthopaedic Department U the Rigshospital The evaluation of the MP was based on the latest clinical and radiographic examination before the operation All examinations were made by the author

Examination of the hip abduction is done with the patient supine on a firm support (*Holt* 1965) Both hips are abducted at the same time first with 90° flexion in the hips and knees then as far as possible with completely extended hip and knee joints Any difference in abduction between the two sides is easily revealed when the supporting surface is firm The abduction is performed slowly and without exerting force It is a well known fact that physiotherapists for example can gradually obtain a greater abduction during treatment than can be got on clinical examination The rapid abduction that reveals the spastic contracture is not of interest in this connection The magnitude of the abduction is evaluated and checked by means of a goniometer As a rule the radiographs are not examined until after the clinical examination

if the best radiological Result is to be obtained on the long term view This requires evalua tion of the stability of the hip on a radiograph as soon as the diagnosis of cerebral palsy is suspected

Comparing the Results of anterior obturator neurectomy with the adductor operations with nearly the same age and preoperative MP it is clear that the Results are of the same magnitude

Elongation of the hip flexors did not provide a better stability of the hip joints on the other hand it is not possible to exclude that operations on the hamstrings or m gracilis might have an importance for the migration of the hip joint

Co en (1968) *Baacke & Tonnis* (1974) and *Bjerkreim* (1974b) have reported cases in which dysplasia has developed in adducted hips where the adduction was due to an abduction in the contralateral hip either the result of an arthrodesis or an uncorrected shortening of the lower extremity

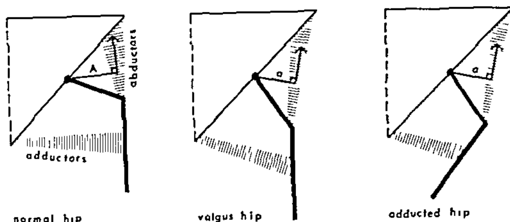


Figure 13
Demonstration of the reduced effect of the abductors in a valgus or adducted hip due to shortening of the lever A

Figure 13 shows that an adducted hip just as in the case of a valgus deformity causes the hip abductors to function inefficiently since the distance from the centre of movement in the head of the femur to the functional axis of the abductors becomes less than that in the normal hip When the lever becomes shorter the moment decreases correspondingly (*Merchant* 1965) This signifies that a temporary faulty position in which the hips are adducted for a period for example in coxitis and Calve Legg Perthes disease could trigger off a self aggravating muscle imbalance

The investigation shows that the correlation between the MP and the hip abduction is poor This must signify that it is not the absolute magnitude of the abduction (= the degree of brevity of the adductors) that bears the primary significance for the hip deformation but the relative imbalance between the hip adductors and abductors that is the deforming force

Example
Pat ent No 33 a boy with spastic and athetoid tetraplegia At the age of 6 years he underwent operation on the left adductors and both mm gracilis Six months before operation the MP in the right hip was 13 per cent in the left hip 50 per cent Six months after the operation the MP was 13 per cent and 93 percent respecti ely Before operation the corresponding hip abduction with leg flexed was 60 in th right hip and 50 in the left hip After operation the abduction was 60 and 70 respectively

Figure 14 shows an example of a hip with considerable subluxation but where there was hardly any brevity of the adductors and where the subluxation disappeared after operation on the adductors

Table 30 Relation between migration percentage and passive abduction of the hip

MIGRATION PERCENTAGE per cent	n	PASSIVE ABDUCTION OF ONE HIP degrees			
		FLEXED LEGS		STRAIGHT LEGS	
		median	range	median	range
MP = 0	20	45	30-90	20	15-50
0 < MP ⩽ 33	114	45	10-85	25	0-60
33 < MP ⩽ 66	44	40	5-65	20	-5-60
66 < MP ⩽ 100	11	25	0-50	15	-5-25
MP ⩾ 0	189	r = -0 35 P < 0 001		r = -0 31 P < 0 001	

Table 30 summarizes the measurements (Tables on p 91) and shows there is a negative correlation between a MP ⩾ 0 per cent and passive hip abduction with flexed and extended legs as r = -0 3 (r is significantly different from 0 P < 0 001) This means that there is only a slight chance of deducing from the degree of hip abduction to the corresponding MP with reasonable certainty and conversely In the individual groups of MPs the range of abduction is seen to be very wide

Discussion

An examination of the literature failed to show any experimental studies that can explain the clinical observation that contractures in muscles and tendons develop in the better functioning of two antagonistic muscle groups in growing subjects Contracture in the adductors is seen for example in children (and dogs *Whittick* 1974) with subluxation of the hip in cases of Calve Legg Perthes disease (but must not be confused here with the initial defense in the adductor muscles) in subluxated hips in patients with myelomeningocele and in children with cerebral palsy As the contracture can develop independently of spasticity the possibility that this might be the causal factor may be ignored This does not deny the experience that the spasticity in cerebral palsy is usually most pronounced in the most powerfully functioning muscle groups and as a result may accentuate a muscular imbalance

The most probable relation appears to be that muscles and tendons only grow in length when they are stretched by a sufficient force which must originate from the antagonist When the antagonist is too week to influence the agonist the latter remains too short in relation to the child s growth (*Sharrard* 1967) As the weaker antagonist is stimulated too much it becomes too long and functions even more ineffectively The imbalance hereby becomes self aggravated (*Sharrard* 1975a) A brevity of the adductors must therefore signify that the adductors function better than the abductors but does not exclude the possibility that both muscle groups may be weak There must therefore be some degree of correlation between the magnitude of the abduction and the MP of the hip This is in fact demonstrated by the investigation as r differs significantly from 0

Conclusion

It is probably correct to conclude that muscles and tendons only grow in length when extended by an adequate force On the basis of this conclusion a brevity of the adductors must imply that these function better than the antagonists = the abductors an imbalance which is self amplifying In a corresponding manner the investigation shows that there is a correlation between the abduction and the MP in a cerebral palsy hip as r differs significantly from 0

However the correlation is only slight as r = -0 3 This implies that it cannot be the brevity in itself that is the primary influence responsible for the outwards migration of the hip The preceding investigations have shown that elongation and weakening of the adductors of the hip exert a positive effect so that it must be the imbalance between the adductors and the more weakly functioning abductors that constitutes the deforming force

The correlation is least when the abduction is measured with extended hips and knees As shown in the previous investigations this suggests that the gracilis muscle has only a slight significance as a deforming force In a corresponding manner the abduction must tell us more about the stability of the hip when measured with 90° flexion in hip and knee

The most important results are that if the abduction is reduced to less than 30° the femoral head as seen on a radiograph must have migrated beyond the rim of the acetabulum and that an investigation of the abduction cannot replace a radiograph of the hip as even a subluxated hip may show abduction up to 60°



½ year before operation
Migration Percentage 50 per cent

½ year after operation
Migration Percentage 23 per cent

Figure 14
Effect of adductor operation on a hip joint with hardly any brevity of the adductors

Sharrard et al found in 1975 in their analysis of patients with limited abduction in the hip measured during extension of hip and knee joint that the greater the instability present in the hip before operation on the adductors the greater the limitation of abduction How ever no correlation was found between abduction and stability of the hip after the opera tion They therefore concluded that full range of abduction was probably not the most im portant factor in obtaining better hip stability Of greater significance was the finding that a balance between abductors and adductors and between flexors and extensors corre sponded better with the maintenance of hip stability In other words the conclusion reached by *Sharrard et al* is the same as in the present study apart from the fact that they involved the flexors and extensors

Leffman in 1959 found that the degree of limited abduction in subluxation did not corre spond to the changes on the radiographic picture and conversely

The correlation with the MP is poorer when the abduction is measured with the legs ex tended and this also tells against the m gracilis playing any real part in the hip deformity It would therefore seem more correct to measure hip abduction with 90° flexion in hip and knee

According to Table 30 the investigation shows that if a cerebral palsy hip can be ab ducted more than 50° the hip is not dislocated and if the abduction is reduced to less than 30° the femoral head does extend beyond the acetabular rim An abduction study cannot replace a radiograph of the hips as a hip which is subluxated may nevertheless have a range of abduction up to 60°

and this makes the use of the MI more complicated The more likely explanation of the greater effect is that muscle imbalance is more pronounced in the poorer hips so that a change in balance obtained by an adductor operation will give a greater Result

The observation that there is no systematic regularity between hip abduction and MP shows once again that a radiographic investigation is necessary if the stability of the hip is to be evaluated

It is known that when oestrogens are given to dogs late in pregnancy or to whelps early after birth this produces laxity in the joint capsule of the hip which may lead to dysplasia or osteoarthrosis (*Gustafson* 1971 and *Whittick* 1974) Most investigators today also regard laxity as the most important factor disposing to congenital dislocation or subluxation in children presenting in the head position at birth (*McKibbin* 1970) *Fredensborg* (1976) found correspondingly that in children who had been treated early for dislocation of the hip the joints were significantly more lax at the age of 10 years than in a corresponding control group

This instability can itself trigger off a muscle imbalance as the effect of the hip abductors is weakened when the femoral head can slide in relation to the acetabulum The restricted hip abduction which can be demonstrated later which is also present when the hip is reduced (*Hart* 1952 *Salter* 1967 *Tanabe et al* 1972 and *Bjerkreim* 1974a) can be regarded as expressing an imbalance between abductors and adductors as found to a more pronounced degree in cerebral palsy *Whittick* (1974) and *Riser* (1974) both found correspondingly that the muscle mass of the abductors is reduced in dysplasia of the hip in dogs

As a consequence of this knowledge instability of the hip joint in the childhood might be treated with an elongation and weakening of the adductors in the presence of brevity of these muscles

We know from many investigations that an unstable hip in infancy and childhood is followed by osteoarthrosis in the adult and *Weickert* in 1975 estimated that 10 to 20 per cent of all newborn infants had hip changes varying from dysplasia to dislocation

However so long as we have not examined the question whether a not completely optimal hip with a MP of 10 per cent for example at the age of 1 year will result in osteoarthrosis of the hip later on the correct scientific background is not present for too rigoristic claims as to what is the normal hip in the childhood

In myelomeningocele the level of the neural deficit remains the most important determinant of the ability to walk (*DeSouza & Carroll* 1976) A level pelvis and free motion of the hips appear to be more important for the function than reduction of the hips (*Feiwell et al* 1978)

But if we aim at containment at the hips in a patient with myelomeningocele the primary intervention must be to treat the muscle imbalance between the abductors and adductors

General conclusion

1 On the basis of the literature it is shown that the relation of the femoral head to the acetabulum on a radiograph may best be described by means of a *Migration Percentage (MP)* by measuring the percentage of the head projecting outside Perkins line (= the acetabular edge)

2 The difference between the MP measured in neutral rotation and in internal rotation of

Chapter VIII

General discussion

As the preceding analyses were carried out on children operated on for the sequelae of cerebral palsy the aim of the present study might have been to elucidate the various problems presented by the hip joints in these children It was tempting however to use the opportunity to show that the motto on the first page of the study also applies to the hip joint and the surrounding muscles under other circumstances than those of cerebral palsy alone so the scope of the hypothesis was enlarged to hold for all child hips

The most important criticism against such a generalization might well be that in congenital dislocation of the hip the muscles show no spasticity But if by spasticity is understood that the muscles counteract a rapid stretch by reflex action then in that disease of the hip spastic shortening of the adductors are also often found clinically

As remarked in the introduction the bones and joints do not appear to be interested in whether a muscle imbalance is neurogenic or myogenic and as anticipated the results of adductor operations did not differ significantly between para or diplegics and tetraplegics just as there were no differences with regard to intelligence and sex

As to the »cerebral palsy« hip the study has shown that muscle imbalance between more weakly functioning abductors and adductors causes the hip to migrate outwards in the years *of infancy and childhood As a result some hips will dislocate any ambulatory capacity* present will be lost and the children will have to undergo the period of pain often followed by severe subluxation and dislocation in cerebral palsy (*Samilson et al* 1972 and *Sharrard et al* 1975)

The study shows that the Results are best following the first operation on the adductors However the Results of any possible secondary operation are not so poor that such operations should be omitted altogether but occasionally when the abductors are very weak a *varus osteotomy of the femur should be included as an alternative* in the considerations

Nor should a unilateral adductor operation be omitted if it is necessary to create a balance at the hip pelvis or spinal column On the other hand elongation of the hip flexors m gracilis or hamstrings should not be performed for the sole purpose of improving hip stability

The unexpected reverse Result following an operation to improve gait such as elongation of the tendo Achilles is merely a further indication that vertical loading of the hip in itself *has no positive effect on the hip* stability

The observation that the Result of adductor operation is greatest in children under the age of 4 years can be explained by the more rapid regeneration of the acetabulum and surroundings the younger the child

The greater effect obtained in the case of a large *preoperative MP might be due to a* built in fault in the calculation of the Results of the MIs as no distinction has been made as to whether an improvement of say 10 per cent/year is from a MP of 60 per cent to 50 per cent or from 30 per cent to 20 per cent However by taking the ratio of the MI to the mean value between preoperative and postoperative MP the Results are not altered essentially

and this makes the use of the MI more complicated The more likely explanation of the greater effect is that muscle imbalance is more pronounced in the poorer hips so that a change in balance obtained by an adductor operation will give a greater Result

The observation that there is no systematic regularity between hip abduction and MP shows once again that a radiographic investigation is necessary if the stability of the hip is to be evaluated

It is known that when oestrogens are given to dogs late in pregnancy or to whelps early after birth this produces laxity in the joint capsule of the hip which may lead to dysplasia or osteoarthrosis (*Gustavson* 1971 and *Whittick* 1974) Most investigators today also regard laxity as the most important factor disposing to congenital dislocation or subluxation in children presenting in the head position at birth (*McKibbin* 1970) *Fredensborg* (1976) found correspondingly that in children who had been treated early for dislocation of the hip the joints were significantly more lax at the age of 10 years than in a corresponding con trol group

This instability can itself trigger off a muscle imbalance as the effect of the hip abduc tors is weakened when the femoral head can slide in relation to the acetabulum The re stricted hip abduction which can be demonstrated later which is also present when the hip is reduced (*Hart* 1952 *Salter* 1967 *Tanabe et al* 1972 and *Bjerkreim* 1974a) can be re garded as expressing an imbalance between abductors and adductors as found to a more pronounced degree in cerebral palsy *Whittick* (1974) and *Riser* (1974) both found corre spondingly that the muscle mass of the abductors is reduced in dysplasia of the hip in dogs

As a consequence of this knowledge instability of the hip joint in the childhood might be treated with an elongation and weakening of the adductors in the presence of brevity of these muscles

We know from many investigations that an unstable hip in infancy and childhood is fol lowed by osteoarthrosis in the adult and *Weickert* in 1975 estimated that 10 to 20 per cent of all newborn infants had hip changes varying from dysplasia to dislocation

However so long as we have not examined the question whether a not completely op timal hip with a MP of 10 per cent for example at the age of 1 year will result in osteo arthrosis of the hip later on the correct scientific background is not present for too rigoristic claims as to what is the normal hip in the childhood

In myelomeningocele the level of the neural deficit remains the most important determi nant of the ability to walk (*DeSouza & Carroll* 1976) A level pelvis and free motion of the hips appear to be more important for the function than reduction of the hips (*Feiwell et al* 1978)

But if we aim at containment at the hips in a patient with myelomeningocele the primary intervention must be to treat the muscle imbalance between the abductors and adductors

General conclusion

1 On the basis of the literature it is shown that the relation of the femoral head to the ace tabulum on a radiograph may best be described by means of a *Migration Percentage (MP)* by measuring the percentage of the head projecting outside Perkins line (= the acetabular edge)

2 The difference between the MP measured in neutral rotation and in internal rotation of

the femur is shown to be so small that it does not justify an examination in both rotations when carrying out a radiographic investigation of the stability of the hip

3 For a hip to be »optimal« in children under the age of 4 years it is shown that the femoral head should not reach further than Perkins line Between the ages of 4 and 16 years at most 5 per cent of the visible part of the femoral head is beyond this line This concept of the optimal« hip is only used provisionally

4 It is shown that a CE angle $< 20^\circ$ in a child over the age of 4 years indicates that the hip is not »optimal« whereas a CE angle $\geqslant 20^\circ$ tells us nothing certain as to the stability of the hip

5 It is shown that the rate of migration in a »normal« child hip is less than 1 per cent per annum

6 It is shown that the subluxated hip in cerebral palsy is aquired and that in such hips the spontaneous migration is a median value of about 10 per cent per annum

7 The first tenomyotomy of spastic hip adductors in cerebral palsy is shown to result in 57 per cent of the hips retaining or improving their stability in the short run

8 It is shown that during an observation period of 6½ years following possibly several soft tissue operations at the hip the stability is retained or improved in about 33 per cent of the hips on the basis of a comparison with the primary radiographic investigation and is im proved in about 70 per cent of the hips in relation to the maximum MP experienced by the hip during the period of observation

9 It is shown that operation should be carried out on the »cerebral palsy« hip without allow ing a period of observation to elapse as soon as a subluxation is noted in order to achieve the best possible final result as evaluated by the radiograph For this reason the MP should be evaluated from a radiograph of the hips as soon as the diagnosis is suspected

10 It is shown that resection of r anterior n obturatorius gives an improvement in the hip stability of the same magnitude as the adductor operation

11 In this analysis there has been no effect of elongation of the hip flexors including the mm iliopsoas rectus and sartorius on the hip stability and no significant Result of the m gracilis resection could be shown However it is not possible to exclude some effect of the proximal elongation of the hamstrings

12 The stability of the hip is shown to become poorer following elongation of the tendo Achilles This suggests that a quantitative increase in the ambulatory capacity may accen tuate an existing muscle imbalance when the gait is not improved qualitatively

13 It is shown that improvement after operations subsequent to the first adductor opera tions is only less than half of that obtained in the first operation

14 It is shown that adductor operation on one hip does affect the contralateral hip with a reverse Result about one third of the Result obtained on the ipsilateral side

15 Differentiation between para or diplegia and tetraplegia or between sex and IQ is not shown to have any significant effect on the Result of adductor operations as evaluated by an investigation of the radiograph of the hip

16 Following adductor operations there is shown to be a significantly greater improvement in the stability of the hip in spastic children under the age of 4 years compared to those over the age of 4 years and the Result is shown to be greatest with a preoperative MP more than 40 per cent These two factors appear to carry same weight

17 It is shown that there is only a slight correlation between the degree of abduction in an untreated cerebral palsy hip and the corresponding MP The clinical investigation can therefore not replace a radiographic investigation as a hip may be subluxated even though it can experience 60 abduction with 90 flexion in hip and knee at the same time

18 It has been shown with the aid of the cerebral palsy hip that the head of the femur can be made to migrate inwards in relation to the acetabulum following an adductor operation and it has been shown in addition that the interventions which often accompany the opera tion such as lengthening of the m gracilis hip flexors and hamstrings result at the most in a minor effect This must signify that it is either the lengthening or the resulting weakening of the adductors that has the greater significance for the improvement in hip stability As it has thus been demonstrated that anterior obturator neurectomy has an effect similar to that obtained by tenomyotomy of the adductors and that there is only a slight relation between the magnitude of the brevity of the adductors and the stability of the hip it may be con cluded that our original hypothesis is correct That is that in the growing child there is a connection between the position of the head of the femur in relation to the acetabulum and the function of the surrounding muscles In addition the investigation has shown that it is especially the balance between the hip adductors and abductors that has significance for the hip stability in the frontal plane as weak abductors in contrast to better functioning adductors result in the femoral head migrating outwards in relation to the acetabulum

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be used As the correlation coefficient between MP and CE angle is only -0 76 a new normal material of MPs was prepared based on measurements of the hip joint on a larger number of urographs From this material patients were excluded with Wilms tumour and neuromuscular diseases as well as children with infections of the urinary tract in the first year of life and only films of the hip in neutral abduction adduction were used As the starting material consists of children with suspected or manifest urological disease the material in spite of selection must be biased by hips which are not optimal (Table 3)

In children under the age of 4 years the observation that in 102 out of 108 hip joints the femoral head is completely covered by the acetabulum indicates that Perkins line represents the maximum lateral position for the femoral head in the optimal hip In children between the ages of 4 and 16 years at most 5 per cent of the visible part of the femoral head is lateral to Perkins line in the optimal hip thus being the finding in 159 out of 247 hips i e not quite ⅔ This concept is only a provisional one i e until we know more about the relation between the MP and coxarthrosis

A comparison between measurements of the same hip joints using CE angles and MPs (Table 4) gives as result that a CE angle $< 20°$ indicates that the hip in a child above the age of 4 years is not optimal On the other hand it is not possible with certainty to reach any conclusion as to the stability of the hip in childhood when the CE angle is $\geqslant 20°$ In accordance with that uncertainty the correlation between the CE angles $\geqslant 20$ and the MPs is only 0 282

The following terms are then defined *Migration Percentage (MP)* the fraction (expressed in per cent) of the visible part of the femoral head which on an a p radiograph has migrated beyond Perkins line (~ acetabular rim) The measurements are made along a line horizontal to the pelvis *Migration* the difference between two instantaneous MPs determined at two different times *Subluxation* the MP is at least 33 per cent *Dislocation* the MP is 100 per cent *Dysplasia* the term is used during the period before the femoral head has become visible on a radiograph and signifying that the acetabulum is sloping with a retreating border as if it had been squeezed during growth

A method is then described of recording the course of the migration in a coordinate system with MP against time (Fig 5)

In order to visualize those changes in the MP of the hips resulting from treatment a coordinate system may be used with the same units in both coordinates (Fig 6)

Chapter IV Table 3 shows the spontaneous migration of the normal hip which is less than 1 per cent per annum The Table also shows that the normal hip does not subluxate

Out of a total of 441 patients with cerebral palsy admitted to the Orthopaedic Hospital in Copenhagen during the period January 1st 1968 to July 1st 1971 those 38 children under the age of 19 years are selected who had a subluxation of the hip during that period and who for that reason underwent an operation on the adductors possibly combined with other soft tissue operations but not at the same time with elongation of the hamstrings or osteotomy of the femur

In 39 cases the number of radiographs are adequate to determine the migration of the hips before and after the first adductor operation An investigation of these hips shows that the subluxation was most often acquired (Fig 7 and Table 5) and after the first adductor operation most of the hips migrated inwards again (Fig 8 and Table 6)

Sharrard et al found in 1975 that *after the first* adductor operation stability was improved or maintained in 75 per cent of the hips Their investigation is confirmed by an analysis of the above 39 hips together with 18 *hips without* preoperative observation (Fig 9 and Table 8) with a result of 57 per cent The investigation also shows that if treatment is decided on from the radiograph alone the operation must be performed as soon as there is an

The extreme shows us
the way to the norm

Summary

Hypothesis In the growing child there is a connection between the position of the head of the femur in relation to the acetabulum and the function of the surrounding muscles In particular it is the balance between the adductors and the abductors of the hip that is of significance for the stability of the hip in the frontal plane

Chapter I By an investigation of the hip in myelomeningocele it is shown that acquired dislocation of the hip may develop when a muscular imbalance is present with adductors and flexors functioning better than abductors and extensors

Experiments on hip models provide no demonstration of what happens in growing individuals Experiments on the young of animals have shown that the hamstrings exert a dislocating effect when the hips are flexed and at the same time the knee joints are maintained extended for some length of time However no investigator has demonstrated which muscle imbalance is of more significance under ordinary conditions A valgus hip appears to develop due to impaired osteogenesis in the epiphysis of the trochanter major the result of diminished stimulation by the hip abductors when their function is reduced

A review is presented of the most important literature on the hip joint in cerebral palsy Some studies show that a relation does exist between the stability of the hip and the function of the sorrounding muscles Muscle imbalance with contracture in the adductors flexors m gracilis and hamstrings is cited as dislocating factor Further factors mentioned as causing dislocation of the hip are coxa valga »status hypoplasticus« and retained neonatal reflexes

It should be possible to test the hypothesis presented by examining the results of lengthening and weakening various muscle groups around the hip joints in children with cerebral palsy This could be done by measuring the stability of the hip on a radiograph before and after operation since an examination of the extreme cases will help to elucidate minor deviations from normal

Chapter II Based on the literature a review is provided of the most familiar methods of measuring the stability of the hip in the frontal plane It is concluded that the relation of the head of the femur to Perkins line (Fig 2) is the best way of indicating the stability of the hip among other reasons because the relation is independent of any pelvic tilt around a horizontal axis so that a urograph for example can also be used for the measurement That visible part of the femoral head which has migrated beyond Perkins line is expressed as a percentage of the width of the entire head and is designated the *Migration Percentage (MP)*

It is shown (Table 1) that the measured difference in MP between internal rotation and neutral rotation of the same hip joint is so small that there are no indications for determinations in both rotations when making a radiographic investigation of the MP of the hip

Chapter III The literature does not contain a normal material of hips measured in relation to Perkins line An investigation was therefore made of the correlation between MP and CE angle (Table 2) to determine whether a normal material based on this measurement could

tendo Achilles adds support to the theory of muscle imbalance as a cause of hip migration since a quantitative improvement in gait may accentuate the already existing imbalance when the use of the muscles are not improved qualitatively at the same time

Chapter VI It has now been shown that soft tissue operations may influence the migration of the cerebral palsy hip and that the best Results were obtained by lengthening and weakening of the adductors The adductor operations are therefore analyzed in greater detail in the same way as the soft tissue operations were in Chapter V

The first adductor operation gave a median Result of 15 per cent/year (Table 19) while secondary operations gave only 6 5 per cent/year (Table 20)

Unilateral operations among first and secondary operations gave a Result of 11 per cent/year (Table 22) but it seems that the operation exerting a negative influence on the unoperated hip with the non significant Result of -4 per cent/year (Table 23)

The Result of the adductor operations was unaffected by whether the children were para og diplegics or tetraplegics (Table 24) whether they were under the Care of the Danish National Service for the Mentally Retarded or not (Table 25) or whether they were boys or girls (Table 26)

On the other hand the best Results were obtained when the children were under the age of 4 years (Table 27) and when the preoperative MP was more than 40 per cent (Table 28) without it being possible to decide which factors were most significant (Table 29)

The Result of gracilis resections alone is a median value of 2 per cent/year but the fact that in these operations the preoperative MP was only 21 per cent may explain this doubtful Result as in that proportion of the adductor operations where the preoperative MP was likewise less than 40 per cent the Result obtained 5 per cent/year is of the same order of magnitude as in the gracilis resections However the median age at the adductor operations was greater than in the gracilis operations Both statically and dynamically the gracilis operation would not be expected to have any significance as it can only influence the hip when the knee is extended so that it can be the postoperative splintage with abducted legs that has been responsible for the doubtful although positive Result

Chapter VII In order to decide the significance of contracture in the adductors for the MP of the hip the hips were investigated in 95 children prior to the first operation on the adductors and the measurements are correlated with the MP of the *corresponding hips* The measurements were made with 90 per cent flexion in the hip and knee as well as with extended leg to elucidate further whether there is any effect of the gracilis muscle on the hip

Clinical experience shows that muscles and tendons must be subjected to stretch by a certain force in order to grow in length When the agonist is too weak to influence the antagonist the latter must remain contracted in relation to *the growth of the child* and as a result the imbalance becomes aggravated A relation would therefore be anticipated between abduction and MP in the hip as brevity of the adductors must signify that the abductors function more weakly

The result of the investigation (Table 30) is that as expected there is a significant correlation but as this is only 0 35 it signifies that *the brevity is not the primary deforming force* The correlation is least when the abduction was measured with legs extended suggesting that the gracilis does not have any great significance for the containment of the hip so that an investigation of the abduction is best *made with flexed hip* and knee joint

A sketch (Fig 13) shows how an adduction contracture in a hip can trigger off such a muscle imbalance It is also shown in a case *history (Fig 14)* how an adductor operation can reduce a dislocated hip in spite of the almost complete absence of brevity in the adductors

indication of commencing subluxation as the hips did not improve spontaneously and as the first adductor operation did not convert subluxated hips into »optimal« hips

An investigation of the hips in all 38 patients before and after all soft tissue operations shows that with a median period of observation of 6½ years 3 hips had become dislocated in spite of the operations and that one hip had been reduced 33 per cent of the hips had improved or maintained their position in relation to the spontaneous migration In relation to the maximum MP experienced 71 per cent improved as a result of operations on muscles and tendons (Table 10 and Figs 10 and 11)

In view of the observation that the stability improved in 20 out of the 25 hips which had migrated more than 50 per cent out of the acetabulum it is concluded that this justifies the effort involved in the treatment without consideration of the level of intelligence and the ambulatory capacity as a dislocation in this group of patients has a considerably incapacitating effect and increases their need for nursing care

Chapter V Since adductor operations are often combined with other soft tissue operations these operations are therefore analyzed as single interventions In order to be able to evaluate changes in MP in relation to time the concept *Migration Index (MI)* is introduced signifying the amount by which the MP of a hip has changed in one year The MI is negative if the femoral head migrates outwards and positive if it migrates inwards The change in preoperative and postoperative MIs thus indicates the *Result of Treatment* expressed as a percentage/year

A total of 1700 children with cerebral palsy have been treated in the Outpatient Department for Handicapped Children at the Rigshospital since 1950 Among those children those 10 are selected who has undergone a total of 19 single gracilis resections a radiographic observation of the hip migration being required both preoperatively and postoperatively The Result found is that the migration of the hips following operation had improved non significantly by 2 per cent/year in relation to the migration prior to operation (Table 12)

A corresponding analysis of 10 resections of the anterior branch of the obturator nerve shows an significant improvement of 4 per cent/year (Table 13) and an examination of the 22 elongations of the hip flexors including the iliopsoas all of which satisfies the above criteria for selection gives a Result of 0 per cent/year (Table 14)

Among those patients at the Orthopaedic Hospital who between 1969 and 1971 underwent a proximal elongation of the hamstrings a total of 43 operations are investigated which satisfies the criteria The significant Result is a median value of 1 per cent/year (Table 15)

Since various soft tissue operations are often performed together with gracilis resection the total of 75 operations are grouped into those with and without simultaneous gracilis resection The Result shows a median effect of 1 per cent/year when the gracilis was involved and 1 per cent/year when the gracilis was not involved at the same time (Table 16)

An operation to improve ambulation such as lengthening of the tendo Achilles is analyzed in a material of 21 operations and gives the unexpected significant Result that the migration was increased by a median value of 4 per cent/year (Table 17)

The positive Result of resection of the anterior branch of the obturator nerve support the finding in Chapter IV that the function of the adductor muscles is of great importance for the migration of the hip joint

The absence of any effect of lengthening the hip flexors agrees with clinical experience that the m iliopsoas in particular does not influence hip migration The poor Result of operations on the hamstrings does not exclude the possibility that these muscles may provoke prenatal dislocation of the hip in frank breech presentation as all the children examined were over the age of 4 years The negative Result following lengthening of the

Gennem det ekstreme erfarer vi
om de mindre afvigelser
fra det normale

Resumé

Hypotese Der er sammenhæng mellem caput femoris stilling i forhold til acetabulum og de omgivende musklers funktion i barneårene Specielt er det balancen mellem hoftens adduktorer og abduktorer der har betydning for hoftens stabilitet i frontalplanet

Kapitel I Ved undersøgelsen af hofteleddet ved myelomeningocele er det vist at erhvervede hofteluksationer kan opstå når der er en muskulær imbalance således at adduktorer og fleksorer fungerer bedre end abduktorer og ekstensorer

Eksperimenter på hoftemodeller kan ikke vise hvad der sker hos voksende individer Ved eksperimenter på dyrebørn er det vist at hamstrings (mm ischiocrurales) virker lukserende når hofterne er flekterede og knæene samtidig holdes ekstenderede i længere tid Men in gen eksperimenter har vist hvilken muskelimbalance der har størst betydning under almin delige forhold Valgushoften synes at opstå ved en nedsat osteogenese i trochanter major epifysen på grund af en mindsket stimulation fra hoftens abduktorer når disses funktion er nedsat

Den vigtigste litteratur vedrørende hofteleddet ved cerebral parese gennemgås Enkelte arbejder viser at der er sammenhæng mellem hoftens stabilitet og de omgivende musklers funktion Muskelimbalance med kontraktur i adduktorer fleksorer m gracilis og hamstrings nævnes som dislocerende faktor Desuden nævnes coxa valga status hypoplasticus og bevarede neonatale reflekser som årsager til hofteluksation

Det må være muligt at undersøge dette arbejdes hypotese ved at analysere resultaterne af forlængelser og svækkelser af forskellige muskelgrupper omkring hofteleddene hos børn med cerebral parese Dette kan gøres ved at udmåle hofternes stabilitet før og efter operationen idet man ved at undersøge det ekstreme kan erfare om de mindre afvigelser fra det normale

Kapitel II På baggrund af litteraturen gennemgås de mest kendte metoder til udmåling af hoftens stabilitet i frontalplanet Det konkluderes at caput femoris relation til Perkins linie (Fig 2) er den bedste måde at angive hoftens stabilitet bl a fordi relationen er uafhængig af en kipning af bækkenet omkring en vandret akse så f eks urografier også kan anvendes Den del af caputkærnen der er migreret uden for Perkins linie udtrykkes i procent af hele kærnens bredde og benævnes *Migrations Procenten (MP)*

Det vises (Tabel 1) at den målte forskel i MP ved indadrotation og neutralrotation af det samme hofteled er så lille at den ikke kan indicere at man ved en radiologisk undersøgelse af hoftens MI foretager undersøgelsen i begge rotationer

Kapitel III Der findes i litteraturen ikke et normalmateriale af hofter udmålt i forhold til Perkins linie derfor undersøgtes korrelationen mellem MP og CE vinkel (Tabel 2) for om muligt at kunne anvende disse normalmaterialer Da korrelationskoefficienten mellem MP og CE vinkel kun er 0 76 fremstilledes et normalmateriale af MPr idet et større antal hofteled blev udmålt på urografier Herfra blev patienter med Wilms tumor neuromusku

prior to operation

The only information that the abduction can provide as to the stability of the hip is that if the passive abduction is reduced to below 30° the femoral head must have migrated outside the acetabular edge A clinical investigation cannot replace a radiographic investigation of the hips as a hip may well be subluxated in a few cases in spite of a range of abduction up to 60°

Chapter VIII In the GENERAL DISCUSSION the most significant results of the investigations are discussed and correlated with the treatment of some of the diseases of the hip in children

In children with cerebral palsy the best Results of adductor operations were obtained at the first operation in children under the age of 4 years and where there was a considerable preoperative MP At the same time however clinical experience shows that this is the group of patients in whom treatment is most difficult in the years of childhood In spite of treatment some of these hips become dislocated after a period of pain and any ambulatory capacity present will be lost

The majority of investigators today consider that laxity of the joint capsule of the hip disposes to congenital subluxation or dislocation When the femoral head is not centered in the acetabulum the effect of the abductors is weakened so that muscle imbalance develops This explains the brevity of the adductors often present later in the course of the disease even after a hip has been reduced following a dislocation Congenital instability of the hip joint might therefore be treated with an elongation and weakening of the adductors in the presence of brevity in these muscles

We know that a relationship exists between osteoarthrosis of the hip and an unstable hip in infancy However so long as we have not examined the relation between MP and osteoarthrosis no basis exists for too rigorous claims as to what is the »normal« hip in children

If we in myelomeningocele aim at containment of the hip joints the primary intervention must be to treat a present muscle imbalance between weak abductors and stronger adductors by for example a tenomyotomy of the adductors

In the GENERAL CONCLUSION the results of the various investigations are set out

In brief it has been shown with the aid of the »cerebral palsy« hip that the head of the femur can be made to migrate inwards in relation to the acetabulum after an adductor operation and it has been shown in addition that the interventions which often accompany the above operation such as lengthening of the m gracilis hip flexors and hamstrings have at most minor effects This must signify that it is either the lengthening or the resulting weakening of the adductors that has the greater significance for an improvement in hip stability As it has thus been demonstrated that anterior obturator neurectomy has an effect similar to that obtained by adductor operations and that only a slight relation exists between the magnitude of the brevity of the adductors and the stability of the hip it may be concluded that the hypothesis originally presented is correct

That is that in the growing child there is a connection between the position of the femoral head in the acetabulum and the function of the surrounding muscles In addition the investigation has shown it is in particular the balance between hip adductors and abductors that has significance for the containment of the hip in the frontal plane as weak abductors in contrast to better functioning adductors result in the femoral head migrating outwards in relation to the acetabulum

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That is that in the growing child there is a connection between the position of the femo ral head in the acetabulum and the function of the surrounding muscles In addition the investigation has shown it is in particular the balance between hip adductors and abductors *that has significance for the* containment of the hip in the frontal plane as weak abductors in contrast to better functioning adductors result in the femoral head migrating outwards in relation to the acetabulum

50% uden for acetabulum konkluderes at dette retfærdiggør indsatsen ved behandlingen uafhængigt af intelligens og gangevne idet en luksation forringer denne gruppe af patienter betydeligt og øger plejebehovet

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Ved en tilsvarende analyse af 10 resektioner af forreste gren af n obturatorius findes et Resultat på 4%/år (Tabel 13) og ved undersøgelse af de 22 forlængelser af hoftefleksorer incl iliopsoas der opfylder udvælgelseskriterierne er Resultatet 0%/år (Tabel 14)

Blandt de patienter der på Ortopædisk Hospital i København fra 1969 til 1971 fik udført en proksimal forlængelse af hamstrings undersøges de 43 operationer der opfylder kriterierne Resultatet er i middel 1%/år (Tabel 15)

Da de forskellige bløddelsoperationer ofte bliver udført samtidig med en gracilis resektion opdeles de ialt 75 operationer i dem med og dem uden samtidig gracilis resektion Resultatet bliver at middel effekten er 1%/år når gracilis var medinddraget og 1%/år når gracilis ikke samtidig blev reseceret (Tabel 16)

En gangforbedrende operation som en forlængelse af Achillessenen er det analyseres efter 21 operationer og giver det uventede signifikante Resultat at migrationen i middel øges 4% om året (Tabel 17)

Det signifikante positive Resultat af resektion af den forreste gren af n obturatorius svarer til resultatet af undersøgelserne i Kapitel IV at funktionen af adduktorerne har en stor betydning for hoftens migration

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Den første adduktor operation gav et Resultat på i middelværdi 15%/år (Tabel 19) hvorimod reoperationer kun gav 6 5%/år (Tabel 20)

De ensidige operationer blandt alle adduktor operationerne gav et middel Resultat på 11% år (Tabel 22) men samtidig påvirkedes den modsatte ikke opererede hofte i negativ retning med et Resultat på 4%/år (Tabel 23)

Det havde ingen betydning for Resultatet af adduktor operationerne om børnene var para eller diplegikere eller tetraplegikere (Tabel 24) om de var under Åndssvageforsorgen

lære lidelser og børn med urinvejsinfektioner fra det første leveår ekskluderet og kun hofte billeder i neutral abduktion adduktion blev anvendt Da udgangsmaterialet er børn med suspekt eller manifest urologisk lidelse må materialet trods selektion være belastet af hofter der ikke er »optimale« (Tabel 3)

Hos børn under 4 år findes at caputkærnen er helt dækket af acetabulum i 102 af 108 hofteled hvilket må betyde at Perkins linie repræsenterer den maksimale laterale begrænsning for caputkærnen ved den »optimale hofte i denne aldersgruppe Fra 4 til 16 års alderen må højst 5% af kærnen nå uden for linien hvis hoften skal anses for at være »optimal« idet *dette er tilfældet i 159 af 247 hofter svarende til næsten ⅔ af hofterne* Denne begrænsning er kun foreløbig til vi ved mere om relationen mellem MP og coxarthrose

Ved en sammenligning mellem de samme hofters CE vinkler og MPr findes at en CE vinkel < 20° angiver at hoften hos et barn over 4 år ikke er »optimal« (Tabel 4) Derimod udtrykker *en CE vinkel ⩾ 20° intet sikkert om hoftens stabilitet Tilsvarende findes en korrelationskoefficient* på kun -0 282 mellem CE vinkler ⩾ 20° og de tilsvarende MPr

Derefter defineres terminologien *Migrations Procenten (MP)* angiver hvor stor en del af caputkærnen (udtrykt i procent) der på et frontalt røntgenbillede af hofterne er vandret uden for Perkins linie (= acetabularranden) Udmålingen *foretages horisontelt i forhold* til bækkenet *Migrationen* defineres som forskellen mellem to MPr udmålt på to forskellige tidspunkter *Subluksation* betyder at MP er mindst 33% *Luksation* og *dislocation* betyder at MP er 100% *Dysplasi* anvendes i perioden for caputkærnen endnu er synlig og betyder at acetabulum er stejl med en vigende rand som var den blevet presset under væksten

Det vises herefter hvordan forløbet af hofternes vandring kan registreres i et koordinatsystem med MPr i relation til tiden (Fig 5) Resultatet af operationerne angivet ved en ændring af hofternes migration kan visualiseres i et diagram hvor begge akser har samme enhed (Fig 6)

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Sharrard et al fandt i 1975 at den første adduktor operation resulterede i at 75% af hofterne fik stabiliteten bedret eller vedligeholdt Deres undersøgelse bekræftes ved en analyse af de foregående 39 hofter samt 18 hofter uden præoperativ observation (Fig 9 og Tabel 8) med et resultat af operationen på 57% Desuden viser undersøgelsen at hvis man vil le behandle alene på et røntgenbillede bør man operere så snart man konstaterer en truende subluksation idet hofterne ikke bedredes spontant og idet den første adduktor operation ikke ændrede sublukserede hofter til optimale hofter

En undersøgelse med i middel 6½ års observationstid af alle 38 patienters hofter før og efter alle bløddelsoperationer viser at 3 hofter lukserede trods operationer og én hofte blev reponeret 33% af hofterne var bedret eller bevaret på plads i forhold til den spontane migration I forhold til den maksimale *MP hofterne var sæde for var 71% bedrede alene ved* muskel og seneoperationer (Tabel 10 og Fig 10 og 11)

På baggrund af at stabiliteten bedredes hos 20 af de 25 hofter der var vandret mindst

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tomi på adduktorerne ved tilstedeværende brevitet af disse

Vi ved at der er en relation mellem hoftearthrose og en instabil hofte i barndommen Men så længe vi ikke har undersøgt sammenhængen mellem MP og arthrose er der ikke baggrund for at være for rigoristiske i vores krav til den normale barnehofte

Hvis vi ved myelomeningocele ønsker at bevare hofterne stabile må den primære behandling være at behandle en tilstedeværende imbalance mellem svage abduktorer og stærkere adduktorer med for eksempel en tenomyotomi på adduktorerne

GENEREL KONKLUSION hvor resultaterne af de forskellige undersøgelser refereres

Til slut sammenfattes at det ved hjælp af den cerebral paretiske hofte er vist at caput femoris kan bringes til at vandre indad i forhold til acetabulum efter en adduktor operation og at det desuden er vist at de ofte ledsagende indgreb som en forlængelse af m gracilis hoftefleksorer og hamstrings højst har en mindre effekt Dette må betyde at det enten er forlængelsen eller den samtidige svækkelse af adduktorerne der har den største betydning for bedringen af hofternes stabilitet Da det desuden er vist at en neurectomi af n obturatorius forreste gren har en effekt af samme størrelse som en adduktor operation og da det er vist at der kun er en ringe sammenhæng mellem graden af brevitet af adduktorerne og hoftens stabilitet kan man konkludere at hypotesen er sand

Det vil sige at der er sammenhæng mellem caput femoris stilling i forhold til acetabulum og de omgivende musklers funktion i barneårene Desuden er det fremgået af undersøgelserne at det specielt er balancen mellem hoftens adduktorer og abduktorer der har betydning for hoftens stabilitet i frontalplanet idet svage abduktorer i forhold til bedre fungerende adduktorer bevirker at caput femoris vandrer udad i forhold til acetabulum

eller ej (Tabel 25) og om de var piger eller drenge (Tabel 26)

Derimod findes at de bedste Resultater opnåedes når bornene var under 4 år (Tabel 27) og den præoperative MP var over 40% (Tabel 28) uden at det kan afgøres hvilken faktor der havde den største betydning for Resultatet (Tabel 29)

Resultatet af gracilis resektionerne er i middel 2%/år *men det at den præoperative MP* ved disse operationer kun var 21% kan forklare det tvivlsomme Resultat Idet Resultatet af den del af adduktor operationerne hvor den præoperative MP ligeledes var under 40% er i samme størrelsesorden på 5%/år Dog var middel alderen større ved adduktor operationerne end ved gracilis resektionerne Statisk og dynamisk ville man ikke vente nogen betydning af m gracilis på hofteleddet da musklen kun er udspændt når knæet ekstenderes og det kan derfor være den postoperative bandagering med abducerede ben der har bevirket det tvivlsomme men dog positive Resultat

Kapitel VII For at afgøre betydningen af en tilstedeværende forkortning af adduktorerne for hoftens MP blev 95 børns hofteled undersøgt for den første adduktor operation og målingen sættes i relation til den tilsvarende hoftes MP Målingerne blev udført med 90° fleksion i hofte og knæ samt med ekstenderede ben for eventuelt yderligere at kunne belyse m gracilis indflydelse på hoften

Ud fra kliniske erfaringer skal muskler og sener udspændes med en vis kraft for at kunne vokse i længden Når agonisten er for svag til at påvirke antagonisten må denne i forhold til barnets vækst blive for kort og dette forværrer imbalancen Man vil derfor vente at der er en sammenhæng mellem hoftens abduktion og MP idet en brevitet i adduktorerne må betyde at abduktorerne er svagere fungerende

Undersøgelsen gav som resultat (Tabel 30) at der som ventet findes en signifikant korrelation men da den kun er -0 35 betyder det at det ikke er breviteten der primært er den deformerende kraft Korrelationen er mindst når abduktionen blev målt med strakte ben dette tyder mod at gracilis har en større betydning for hoftens kvalitet og derfor foretages en undersøgelse af abduktionen bedst med flekterede hofte og knæled

Med en tegning (Fig 13) vises hvordan en adduktionskontraktur i en hofte kan udløse en sådan muskelimbalance Og det vises ved en sygehistorie (Fig 14) hvordan en adduktor operation kan reponere en sublukseret hofte til trods for at der før operationen næsten ikke fandtes brevitet i adduktorerne

Det eneste abduktionen kan fortælle om hoftens stabilitet er at hvis den passive abduktion er nedsat til under 30° må caput femoris være vandret uden for acetabularhjørnet Undersøgelsen kan ikke erstatte en røntgenundersøgelse af hofterne idet en hofte godt kan være sublukseret i enkelte tilfælde til trods for at hoften kan abduceres 60°

Kapitel VIII GENEREL DISKUSSION hvor de væsentligste resultater af undersøgelserne diskuteres og sættes i relation til behandlingen af nogle hoftelidelser i barneårene

Ved cerebral parese opnåedes de bedste radiologiske Resultater af adduktor operationer ved den første operation hos børn under 4 år og ved en stor præoperativ MP Men samtidig er det en klinisk erfaring at det er denne patientgruppe der op gennem årene er vanskeligst at behandle Eventuelt trods behandling lukserer nogle af disse børns hofter efter en periode med smerter og en mulig gangfunktion ophører

Løshed af hofteleddet anses i dag af de fleste for at disponere til den medfødte subluksation og luksation Når caput femoris ikke er centreret i acetabulum svækkes effekten af abduktorerne hvorved der opstår en muskelimbalance Dette forklarer den brevitet af adduktorerne der ofte er *til stede senere i forløbet* selv efter hoften er reponeret efter en luksation

En konsekvens af vores nuværende viden må være at der gøres en tilstrækkelig tenomyo

Relation between CE angle and migration percentage ⩾ 0 per cent I

AGE years	MIGRATION PERCENTAGE per cent	CE ANGLE degrees
4^{2}	0	19
4^{1}	0	20
2^{11}	0	24
2^{11}	0	26
4^{2}	0	26
4^{8}	0	28
5^{9}	0	29
5^{9}	0	34
4^{2}	2	21
3^{5}	2	25
5^{8}	2	29
5	3	29
5^{2}	4	19
4^{8}	4	23
3^{2}	5	17
4^{2}	6	20
1^{10}	6	22
1^{10}	6	23
8^{10}	7	30
2^{2}	8	14
5^{6}	8	18
5^{8}	8	27
7^{4}	8	29
4^{2}	9	18
11^{10}	9	36
11^{10}	9	38
3^{3}	10	17
4^{2}	10	24
1^{10}	11	12
1^{10}	11	15
4^{10}	11	16
3^{5}	11	20
5^{2}	12	17
5^{6}	12	18
8^{10}	12	30
2^{1}	13	14
3^{6}	13	18
5	13	20
2^{10}	13	20
7	13	25
6^{2}	13	26
3^{6}	14	15
5^{3}	14	22
7^{4}	14	30
3^{2}	15	13
4^{3}	15	16
6^{4}	15	16
3^{4}	15	17
4^{7}	15	22
14^{6}	15	33
2^{2}	16	13
6^{4}	16	14
4^{3}	16	15
5^{9}	16	19
5	16	20
2^{10}	16	20
6^{2}	16	22
14^{6}	16	35
2^{11}	17	15
6^{9}	17	20
4^{8}	18	16
4^{10}	18	16
5^{3}	18	17
5^{11}	18	17
6^{11}	18	20
7^{9}	18	26
3^{7}	19	13
4^{8}	19	14
5	19	14
5^{3}	19	15
3^{3}	19	16
7^{8}	19	20
4^{4}	20	13
6^{2}	20	16
5^{9}	20	18
5^{3}	20	18
7	20	18
9^{10}	20	18
8^{10}	20	20
7^{9}	20	27
2^{9}	21	15
5^{11}	21	18
5^{7}	22	14
6^{9}	22	17
9^{10}	22	18
11^{2}	22	19
4^{7}	22	21
11^{2}	22	22
5^{7}	23	12
4^{1}	23	14
7	23	15
4^{3}	24	10

Relation between hip rotation and migration percentage ⩾ 0 per cent

AGE years	MIGRATION PERCENTAGE (*per cent*)			
	RIGHT HIP		LEFT HIP	
	NEUTRAL ROTATION	INWARD ROTATION	NEUTRAL ROTATION	INWARD ROTATION
2^{4}	35	27	35	27
13^{8}	20	18	20	16
1^{11}	17	9	8	0
12^{6}	9	8	7	8
2^{8}	21	18	24	18
8^{2}	25	25	21	21
1^{10}	29	25	13	8
3^{7}	26	31	19	20
3^{6}	38	43	35	31
2^{4}	20	8		
5^{2}	16	12	2	8
3^{5}	6	8	9	8
11^{8}	9	13	15	13
2^{7}	9	8	22	27
4^{10}	5	8	25	14
1^{3}	13	15	23	20
1^{7}	28	24	28	24
7^{5}	13	15	0	1
3^{3}	29	22	23	17
6^{4}	26	22	22	23
4^{7}	22	12	15	8
7^{4}	17	12	10	10
9^{8}	25	23	21	18
2^{7}	24	23	21	8
3	14	21	21	18
11	17	19	20	21
8^{9}	19	21	8	0
5	16	16	3	4
7^{9}	20	15	18	15
7^{8}	19	20	25	23
4^{1}	0	0	0	0
1^{10}	6	3	6	3
7^{4}	14	11	7	13
4^{3}	0	0	18	14

First adductor operations *with* preoperative observation

PT	AGE years		OBSERVATION years	MIGRATION PERCENTAGE per cent		
	PRIM	OP	PREOP	PRIM	PREOP	POSTOP
1	0^{9}	1^{1}	0^{3}	86	100	16
1	1^{6}	2^{3}	0^{9}	18	29	13
4	2^{9}	16^{10}	14	0	16	11
4	2^{9}	16^{10}	14	0	40	35
5	1^{4}	2^{1}	0^{9}	27	39	10
7	1^{10}	2^{7}	0^{5}	33	61	27
8	2^{5}	2^{11}	0^{6}	38	50	31
8	2^{5}	2^{11}	0^{6}	57	61	63
9	1^{6}	2^{6}	1	29	41	30
9	1^{6}	2^{6}	1	28	39	33
10	0^{2}	1^{11}	1^{9}	0	46	40
10	0^{2}	1^{11}	1^{9}	0	27	40
11	2	5^{6}	3^{6}	30	72	29
14	2^{8}	3^{4}	0^{8}	38	43	30
14	2^{8}	3^{4}	0^{8}	25	31	25
16	7^{7}	9^{6}	1^{11}	35	44	41
17	3	5^{11}	2^{9}	20	32	35
17	3	5^{11}	2^{9}	16	35	35
18	5^{9}	6^{4}	0^{6}	54	58	53
18	5^{9}	6^{4}	0^{6}	16	17	18
19	5	5^{8}	0^{5}	37	40	31
19	5^{4}	5^{9}	0^{5}	44	40	54
20	17^{4}	18^{8}	1	55	67	30
20	17	18^{8}	1^{4}	24	30	8
22	3^{1}	4^{2}	1^{1}	36	44	39
22	3^{1}	4^{2}	1^{1}	59	56	60
24	4^{6}	5	0^{6}	52	50	41
27	1^{11}	2^{4}	0^{5}	60	64	77
29	0^{8}	4^{3}	3^{7}	0	20	8
29	0^{8}	4^{3}	3^{7}	24	47	26
30	3^{7}	5^{6}	1^{11}	38	58	44
31	11^{2}	12^{3}	1^{1}	55	61	69
32	1^{11}	2^{3}	0^{3}	12	14	23
32	1^{11}	2^{3}	0^{3}	28	33	43
33	2^{10}	6^{1}	2^{9}	33	45	15
34	4	5^{2}	0^{9}	47	52	18
34	5^{2}	6^{9}	1^{7}	56	39	28
37	2	3^{3}	0^{8}	40	43	43
37	2^{7}	3^{3}	0^{8}	22	50	43

Relation between CE angle and migration percentage ≥ 0 per cent II

AGE years	MIGRATION PERCENTAGE per cent	CE ANGLE degrees
2^{11}	24	12
6^{8}	24	14
1^{10}	25	14
7^{8}	25	15
2^{3}	26	8
3^{4}	26	10
6^{8}	26	11
4^{1}	26	12
3^{7}	26	12
2^{9}	26	14
8^{6}	26	16
8^{10}	26	18
2^{1}	27	8
5^{2}	27	9
7^{6}	27	11
4^{4}	27	12

AGE years	MIGRATION PERCENTAGF per cent	CE ANGLE degrees
5^{2}	28	6
4^{1}	28	10
6^{11}	28	11
8^{6}	29	12
7	30	7
6^{2}	30	8
2^{3}	30	10
1^{10}	30	11
7^{5}	33	6
7^{6}	35	6
5^{6}	35	8
5^{6}	39	1
6^{2}	46	0
7^{5}	46	0
6^{2}	47	0

Number of hip joints in groups with different migration percentage and age measured on urographs from »normal« children

AGE years	MIGRATION PERCENTAGE per cent																					
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	22	29	TOTAL
< 4	102			2	2			1							1							108
4≤ < 8	66		3	9	8	5	5	8	6	3	6	2			1	1			1	1	1	126
8≤ <12	17	3	3	6	5	9	5	6	3	4	4	3	3	4	1	1	1					78
12≤ <16	8	1	3	2	6	5	3	1	1	3	1	1	3	1	3				1			43
																						355

Follow up after all muscle and soft tissue operations I

PT	AGE years FINAL	OBSERVATION years	MIGRATION PERCENTAGE per cent PRIM	FINAL	MAX	*a*dductor *h*amstrings *ab*ductor *o*bturator n *g*racilis *r*ectus *p*soas *A*chilles
1	6^{8}	6	86	18	100	a+g+A
1			18	8	29	a+g+h+A
2	9^{10}	7^{11}	42	26	47	a+a+a+g+g+o
2			36	19	50	a+a+a+g+g+o+p+h
3	8^{10}	5^{9}	33	33	37	a+g+A
3			33	44	44	a+g+A
4	21^{3}	18^{8}	0	16	16	a+g+A
4			0	39	40	a+a+g+A
5	6^{3}	5^{1}	13	26	37	a+g
5			27	29	39	a+g+o+abd
6	10^{5}	6	26	18	34	g
6			41	27	45	a+a+g+g+o+o+r+abd+Yount
7	6^{9}	6	33	17	61	a+g
7			7	30	31	g
8	9^{0}	7^{5}	43	28	50	a+a+g+o+h
8			59	26	63	a+a+a+g+o+o
9	10^{9}	9^{3}	29	7	41	a+a+a+g+o+p+h+r
9			28	18	39	a+a+g+p+h+r
10	9^{5}	9^{3}	0	26	46	a+a+g+g+o+h
10			0	25	44	a+a+g+g+o+h
11	9	7^{7}	30	17	72	a+g
11			9	49	49	a+g
12	9^{11}	4^{8}	34	18	34	a+g+o
12			22	21	22	g
13	12^{11}	3^{1}	42	35	42	a+g
13			36	33	36	a+g
14	9^{0}	7^{2}	38	26	43	a+g+o+h+A+A
14			25	21	31	a+g+o+h+A+A
15	16^{10}	9	29	13	29	a+g+o+h+A
15			30	29	40	a+a+g+o+p+h+r+A
16	17^{1}	9^{6}	35	20	44	a+a+g+g+o+p+h
16			21	16	26	g+o+h
17	8^{1}	5^{3}	18	35	35	a+g+g+A
17			15	35	35	a+g+g+A
18	11^{9}	5^{1}	54	46	66	a+ +g+o+p
18			16	13	21	a+g+o+h
19	10^{6}	5	37	43	43	a+g+o
19			44	23	54	a+ +g+g+o+p+h

First adductor operations *without* preoperative observation

PT	AGE years	OBSERVATION years	MIGRATION PERCENTAGE per cent	
	OP	POSTOP	PREOP	POSTOP
2	2	1	42	47
2	2	1	36	50
3	3^{3}	2^{11}	33	37
3	3^{3}	2^{11}	33	37
6	4^{1}	1^{2}	41	17
12	5^{3}	2^{6}	34	17
13	9	2^{8}	42	34
13	9	2^{8}	36	34
23	3^{9}	3^{2}	43	41
23	3^{9}	3^{2}	57	50
25	4^{2}	0^{6}	100	36
26	3	0^{4}	26	26
26	3	0^{4}	63	34
28	5^{11}	1^{4}	90	100
28	5^{11}	1^{4}	81	66
35	7^{4}	2^{8}	50	32
35	7^{4}	2^{8}	64	31
38	5^{10}	2^{9}	33	21

Gracilis resections

PT	AGE years OP	OBSERVATION years PREOP	POSTOP	MIGRATION PERCENTAGE per cent PRIM	PREOP	POSTOP	MIGRATION INDEX per cent/year PREOP	POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS
17	4	1	1	20	29	3	6	3	3	
17	4	1^{8}	1	16	26	3	7	9	2	
34	4	1^{9}	0^{8}	38	47	52	5	7	2	hamstrings dist
34	4	1	0^{8}	15	37	36	13	1	14	hamstrings dist
53	2	0	0^{9}	3	7	5	10	3	13	
53	2^{6}	0^{5}	0^{9}	6	3	8	7	7	14	
56	4	0^{8}	1	21	9	29	11	0	11	
56	4	0^{8}	1	36	9	24	11	2	9	
64	3^{10}	1^{10}	1^{9}	6	11	12	3	1	2	
64	3	1	1	15	15	13	0	1	1	
73	7^{6}	1	2^{4}	13	21	22	5	0	5	
73	7^{6}	1	2^{4}	9	1	18	2	3	1	
113	2^{8}	0^{6}	0^{5}	0	6	11	12	12	0	
113	2^{5}	0^{6}	0^{5}	3	15	17	24	-4	20	
119	4	2	4^{5}	4	15	25	6	2	4	
119	4	2	4^{7}	15	21	30	3	2	1	
120	3	0^{5}	0^{6}	3	16	16	31	0	31	
129	2	0^{9}	1	17	24	19	9	4	13	
129	2	0^{9}	1	25	21	28	5	5	10	

Obturator anterior neurectomies

PT	AGE years OP	OBSERVATION years PREOP	POSTOP	MIGRATION PERCENTAGE per cent PRIM	PREOP	POSTOP	MIGRATION INDEX per cent/year PREOP	POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS
16	11	1	1	40	41	37	1	4	5	
16	11	1	1	22	26	24	4		6	
71	5	1	2	17	26	27	6	0	6	
71	5	1	2	26	31	30	3	0	3	g
100	8^{7}	0^{5}	1	15	18	24	3	4	1	g
100	8^{3}	0^{3}	1	17	19	20	2	1	1	g
122	2	1	2	18	19	10	1	5	6	g
122	2	1	2	24	4	14	0	5	5	
138	8	6^{9}	2	0	10	10	1	0	1	
138	8	6	2^{9}	0	8	10	1	1	0	

Follow up after all muscle and soft tissue operations II

PT	AGE years FINAL	OBSERVATION years	MIGRATION PERCENTAGE per cent PRIM	FINAL	MAX	*a*dductor *h*amstrings *ab*ductor *o*bturator n *g*racilis *r*ectus *p*soas *A*chilles
20	23^{4}	6	55	26	67	a+g+p
20			24	20	30	a+g+p
21			without preoperative X ray			
21						
22	8^{8}	5^{7}	36	38	44	a+a+g+o+o+A
22			59	51	60	a+a+g+o+o+A
23	6^{11}	3^{3}	43	41	46	a+g+o+A
23			57	50	57	a+g+o+A
24	11^{5}	6^{11}	52	49	52	a+g+o
24			0	27	31	g
25	7^{1}	3^{1}	100	23	100	a+g+o+p
25			37	100	100	
26			mors without postoperative X ray			
26						
27	5^{5}	3^{4}	60	77	77	a+g
27			19	100	100	
28	7^{2}	1^{3}	90	100	100	a+g+o+h+A
28			81	66	81	a+g+o+h+A
29	10^{5}	9^{9}	0	13	20	a+g+o+h+abd+Yount
29			24	38	47	a+a+a+g+o+p+h
30	7	3^{5}	38	44	58	a+g
30			6	26	26	mors
31	18^{1}	6^{11}	11	10	15	
31			55	74	74	a+g+p+r
32	9^{10}	8	12	20	23	a+g
32			28	28	47	a+a+g+o
33	12^{9}	9^{11}	6	23	23	a+g+g+abd
33			33	15	45	a+g+o+Yount
34	10^{4}	8	38	17	59	a+g+g+h+A+A
34			15	20	39	a+g+g+h+A+A
35	11^{11}	5^{3}	50	33	50	a+g+o+h+abd
35			64	30	64	a+g+o+h
36	13^{2}	10	29	36	36	a+a+a+g+g+g+A
36			29	43	43	a+g+g+h+A
37	10^{10}	8^{2}	40	32	43	a+a+a+g
37			20	19	50	a+a+a+g+g+o+p
38	12^{11}	7^{4}	20	64	78	a+p
38			33	19	33	a+a+g+o

Proximal elongations of hamstrings

PT	AGE years OP	OBSERVATION years PREOP	POSTOP	MIGRATION PERCENTAGE per cent PRIM	PREOP	POSTOP	MIGRATION INDEX per cent/year PREOP	POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS
9	4	0^{9}	1	30	24	18	8	5	3	
9	4	0^{9}	1^{2}	33	33	30	0	3	3	
40	14	2	3	15	22	12	2	3	5	
40	14	2^{2}	3	28	23	14	2	3	1	
41	6	3^{4}	4	6	16	18	3	1	2	g
41	6	3	4	11	13	18	1	1	0	g
42	12	2	2^{6}	15	18	13	2	2	4	g
43	8	2^{4}	2	16	21	21	2	0	2	g
43	8	2^{4}	2	24	20	17	2	1	1	g
49	11	2^{4}	2^{6}	0	7	12	3	2	1	g
49	11	2^{4}	2^{4}	0	11	11	5	0	5	g
56	10^{1}	1	2	24	21	17	2	2	0	
56	10^{3}	1	2^{6}	25	24	18	1	2	1	
61	13	0^{11}	1^{2}	26	26	20	0	5	5	
61	13	0^{1}	1^{3}	24	21	16	3	4	1	
66	9	0^{4}	1	29	3	27	6	3	9	
66	9^{5}	0^{6}	1	29	31	6	4	3	7	
78	10^{5}	2	2^{4}	24	23	22	0	0	0	
78	10	2^{1}	2^{4}	17	21	19	2	1	1	
79	15	3	2^{8}	8	8	9	0	0	0	
79	15^{2}	3	2	8	13	11	1	1	2	
8	14^{2}	2	1	7	4	8	2	3	5	
82	14	2	1	13	11	11	1	0	1	
89	12	2	0^{1}	7	10	8	1	2	3	g
89	12	2	0^{1}	7	14	13	3	1	4	
93	4	0^{6}	1^{3}	22	2	19	0	2	2	
95	4	0^{6}	1	15	13	11	4	2	2	
97	10^{3}	2	4	16	14	14	1	0	1	
103	1	0^{6}	1	13	10	7	5	3	2	
103	12	0^{9}	1	11	10	7	2	3	1	
115	5	1	2	24	27	21	2	3	5	
11	5	1	2^{2}	26	33	34	3	0	5	
1 1	7	1	2	16	17	17	1	0	1	
121	7^{9}	1	2	11	10	19	0	4	4	
124	4	1	1^{0}	20	20	19	0	0	0	
124	4	1	1	6	3	18	4	8	12	
128	12^{4}	0	1	16	18	15	3	3	6	
128	12	0	1^{3}	13	15	16	4	1	5	
131	11	2	2	20	17	18	1	0	1	
131	11	2	2	21	20	11	0	3	3	
132	15	6	2	20	12	12	1	0	1	
132	15	6	2	15	8	13	1	2	3	
141	8	1	1	19	24	18	4	4	8	g

Elongations of hip flexors

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	PREOP	POSTOP		
45	10^{4}	1^{6}	5^{9}	10	10	14	0	1	1	
45	10^{4}	1^{6}	5^{9}	9	11	14	1	1	0	
87	9^{9}	2^{6}	3	13	11	6	1	2	1	
87	9^{9}	2^{6}	3	16	11	7	2	1	1	
88	14^{6}	5^{4}	0^{8}	20	16	20	1	6	7	
88	14^{6}	5^{4}	0^{8}	11	15	19	1	6	5	
89	7^{5}	3^{7}	3^{6}	7	9	5	1	1	2	g
89	7^{5}	3^{7}	3^{6}	2	5	9	1	1	0	g
98	7^{1}	5^{4}	4^{11}	14	16	19	0	1	1	g
98	7^{1}	5	4^{11}	17	18	13	0	1	1	g
123	6^{2}	0^{10}	1^{1}	16	19	11	4	7	11	g
123	6^{2}	0^{10}	1^{1}	14	16	15	2	1	3	g
125	6^{9}	1^{3}	4^{2}	22	20	21	2	0	2	g
125	6^{9}	1^{3}	4^{2}	30	30	28	0	0	0	g
128	9^{9}	7^{6}	2^{1}	35	2?	18	2	2	0	g
1 8	9^{9}	7^{6}	2^{1}	18	18	15	0	1	1	g
130	13^{9}	0^{7}	1^{2}	22	18	12	7	5	2	
130	13^{9}	0^{7}	1^{2}	26	26	2?	0	3	3	
138	11	2^{9}	5^{11}	10	10	10	0	0	0	
138	11	2^{9}	5^{11}	8	10	1?	1	0	1	
139	1 ^{4}	1^{3}	1^{4}	10	6	6	3	0	3	
139	12	1^{3}	1^{4}	0	0	1	0	1	1	

Proximal elongations of hamstrings

PT	AGE years OP	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent /year	ADDITIONAL OPERATIONS
		PREOP	POSTOP	PRIM	PREOP	POSTOP	PREOP	POSTOP		
9	4	0^{9}	1^{3}	30	24	18	8	5	3	
9	4	0^{9}	1^{3}	33	33	30	0	3	3	
40	14	2^{2}	3	15	2	12	2	3	5	
40	14	2	3	28	23	14	2	3	1	
41	6^{1}	3	4	6	16	18	3	1	2	g
41	6	3^{4}	4	11	13	18	1	1	0	g
42	1	2	2^{6}	15	18	13	2	2	4	g
45	8	2^{6}	2^{5}	16	21	21	2	0	2	g
43	8^{10}	2^{6}	2	24	20	17	2	1	1	g
49	11	2^{4}	2^{6}	0	7	12	3	2	1	g
49	11	2^{4}	2^{6}	0	11	11	5	0	5	g
6	10^{2}	1	2^{9}	24	21	17	2	2	0	
56	10^{3}	1^{1}	2^{6}	25	24	18	1	2	1	
61	13	0^{3}	1	26	26	20	0	5	5	
61	13	0^{3}	1	24	21	16	3	4	1	
66	9^{5}	0^{6}	1	29	3	27	6	3	9	
66	9^{5}	0^{6}	1	29	31	26	4	3	7	
78	10	2	2^{4}	24	23	22	0	0	0	
78	10^{5}	2	2^{4}	17	21	19	2	1	1	
79	15^{2}	3	2	8	8	9	0	0	0	
79	15	3	2^{6}	8	13	11	1	1	2	
82	14^{2}	2	1	7	4	8	2	3	5	
82	14	2	1	13	11	11	1	0	1	
89	12	2^{3}	0^{1}	7	10	8	1	2	3	g
89	12	2	0^{1}	7	14	13	3	1	4	
93	4	0^{8}	1	22	22	19	0	2	2	
93	4	0^{4}	1^{3}	15	13	11	4	2	2	
97	10^{3}	2	4	16	14	14	1	0	1	
103	12	0^{8}	1	13	10	7	5	3	2	
103	12	0^{8}	1	11	10	7		5	1	
115	5	1	2	24	27	21	2	3	5	
115	5	1	2	26	33	34	5	0	5	
121	7^{6}	1	2	16	17	17	1	0	1	
121	7^{6}	1	2	11	10	19	0	4	4	
124	4	1	1	20	20	19	0	0	0	
124	4	1	1	26	32	18	-4	8	12	
128	12^{8}	0^{8}	1	16	18	15	3	3	6	
1 8	1^{9}	0^{9}	1^{2}	18	15	16	4	1	5	
131	11	2	2	20	17	18	1	0	1	
131	11	2	2	21	20	11	0	3	3	
15	15	6	2^{5}	*0	12	12	1	0	1	
132	15	6	2	15	8	13	1	2	3	
141	8	1	1	19	24	18	-4	4	8	g

Tendo Achilles elongations

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	PREOP	POSTOP		
39	7^{3}	0^{7}	1^{5}	10	8	14	3	4	7	
39	7^{3}	0^{7}	1^{5}	17	12	15	9	2	11	
50	5^{3}	1^{7}	1^{4}	18	16	16	1	0	1	
50	5^{3}	1^{7}	1^{3}	11	11	15	0	4	4	
76	3^{7}	1^{6}	1^{11}	33	26	39	5	7	12	
76	3^{7}	1^{6}	1^{11}	7	19	35	8	8	0	
109	2^{7}	0^{9}	0^{10}	30	3°	30	3	2	5	
109	2^{7}	0^{9}	0^{10}	25	15	°2	13	8	21	
116	4^{7}	1^{5}	1^{4}	19	2	20	2	1	3	
116	4^{7}	1^{5}	1^{3}	10	15	16	4	1	3	
123	7^{4}	1	1^{11}	19	11	16	8	3	11	
1°3	7^{4}	1	1^{11}	16	15	15	1	0	1	
145	3^{3}	1^{8}	2^{3}	14	8	12	4	2	6	
146	5	1^{7}	1^{7}	11	16	19	3	2	1	
146	5	1^{7}	1^{7}	2	3	10	1	4	3	
148	4^{1}	2^{5}	3^{6}	0	0	13	0	4	4	
148	4^{1}	2^{5}	3^{6}	0	0	13	0	4	4	
149	3^{8}	1^{9}	2	0	0	8	0	4	4	
149	3^{8}	1^{9}	2	0	0	2	0	1	1	
152	5^{5}	0^{7}	1	19	17	18	3	1	4	
152	5^{5}	0^{7}	1	16	20	21	7	1	6	

The first adductor operations

PT	AGE years OP	OBSERVATION yr PREOP	POSTOP	MIGRATION PERCENTAGE per cent PRIM	PREOP	POSTOP	MIGRATION INDEX per cent /yr PREOP	POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS	DIAGNOSIS	LOW IQ	GIRL
1	1^{1}	0^{3}	1^{2}	86	100	16	56	56	100	g	tet plegı		+
1	2	0^{9}	2^{4}	18	29	15	15	6	21	g	tet pl gı		+
4	16	7	0^{1}	13	16	11	0	5	5	g	dıplegı		+
4	16	7^{3}	0^{1}	16	40	35	3	5	8	g	d plegı		+
5	2	0^{9}	0^{8}	27	39	10	16	44	60	g+o	et plegı	+	+
7	2	0^{9}	1	33	61	34	37	27	64	g	et plegı	+	
8	2	0^{4}	0^{8}	38	50	31	24	29	53	g+o	tet plegı	+	
8	2	0^{4}	0^{8}	57	61	63	8	3	5	g+o	etr plegı	+	
9	2^{4}	1	1	29	41	30	12	9	21	g	dıplegı		+
9	2^{4}	1	1	28	39	33	11	5	16	g	dıplegı		+
10	2	1	2^{9}	0	46	40	26	2	28	g	p aplegıa		
10	2^{1}	1	2^{9}	0	27	40	15	5	10	g	pa aplegıa		
11	5	3	2^{4}	30	72	29	12	18	30	g	tet aplegıa		+
14	3	0^{8}	0^{9}	38	43	33	8	13	21	o	dıplegı		
14	3	0^{6}	0^{9}	25	31	26	9	7	16	o	dıplegı		
16	9^{4}	1	1^{1}	35	44	41	5	2	7	g	et plegı	+	+
17	5	2^{9}	2	20	32	35	4	1	3	g	p aplegıa		+
17	5^{3}	2	2^{3}	16	35	35	7	0	7	g	paraplegı		+
18	6	0^{4}	2^{9}	54	58	53	8	2	10	g+o	dıplegı	+	
18	6	0^{4}	2^{9}	16	17	18	2	0	2	g+o	dıplegı	+	
19	5	0^{5}	0^{8}	37	40	31	7	14	21	g+	t plegıa	+	
19	5	0	0^{8}	44	40	54	10	21	31	g+	et plegı	+	
20	18	1	2^{5}	55	67	30	9	15	24	g+p	dıplegı	+	
20	18	1	2^{5}	24	30	8	5	9	14	g+p	dıplegı	+	
22	4	1	2	36	44	39	7	3	10	g+o	tet plegı	+	+
22	4	1	2	59	56	60	3	2	5	g+o	et plegıa	+	+
24	5	0^{4}	0^{8}	52	50	42	4	12	8	g+o	tet plegı	+	
27	2^{4}	0^{5}	1	60	64	56	10	6	16	g	tet aplegı	+	+
29	4	3	1	0	20	8	6	8	14	g+o	tet plegı	+	
29	4	3	1	24	47	26	6	15	21	g+o	t plegıa	+	
30	5	1	1^{4}	38	58	44	10	9	19	g	tet aplegı	+	
31	12	1	2	55	61	69	4	4	0	g+p+	tet plegı	+	+
3	2	0	1	12	14	23	5	5	0	g	et pleg	+	
32	2	0^{3}	1	28	33	43	12	5	7	g	etr plegıa	+	
33	6	2^{9}	2	33	45	16	4	11	15	g+o	tet aplegı		
34	5^{3}	0	0^{11}	47	52	22	7	33	40	g	dıplegı		+
34	6	0^{8}	0^{1}	37	39	28	3	13	16	g	dıplegı		+
37	3^{3}	0^{6}	0^{3}	40	43	43	5	0	5	g	dıplegı		+
37	3	0^{6}	0^{1}	22	50	43	-4	8	50	g	dıplegıa		+

Secondary adductor operations

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS	DIAGNOSIS	LOW IQ	GIRL
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	PREOP	POSTOP					
2	3^{3}	1	0^{7}	49	47	41	5	10	15	g+o	tetraplegia	+	
2	3^{3}	1	0^{7}	36	50	21	14	50	64	g+o	tetraplegia	+	
	4	0^{7}	1^{8}	47	41	25	10	11	1	g+semitend	tetraplegia	+	
2	4	0^{7}	1^{8}	50	21	29	50	1	51	g+p	tetraplegia	+	
8	3^{9}	0^{8}	0^{11}	61	63	56	3	8	11	semitend	tetraplegia	+	
8	4^{7}	0^{11}	1^{8}	63	56	28	8	19	11	o	tetraplegia	+	
9	3^{8}	1^{2}	0^{9}	41	30	24	9	8	1	o	diplegia		+
10	4^{11}	2^{9}	2	46	40	42	2	1	3	g+o	paraplegia		
10	4^{11}	2^{9}	2	27	40	32	5	4	9	g+o	paraplegia		
15	11^{9}	3^{11}	2^{8}	29	25	21	1	9	1	o	diplegia		
15	11^{9}	3^{11}	2^{8}	30	40	29	3	4	7	o	diplegia		
16	12^{7}	0^{4}	0^{7}	38	37	30	3	12	9	g+p	tetraplegia	+	+
21	7^{8}	2^{8}	2^{7}	28	27	18	0	4	4	g+o	tetraplegia	+	+
21	7^{8}	2^{6}	2^{7}	4	9	18	2	3	1	g+o	tetraplegia	+	+
22	6^{2}	2	1^{8}	44	39	36	3	2	1	o	tetraplegia	+	+
22	6^{2}	2	1^{8}	56	60	49	2	7	9	o	tetraplegia	+	+
32	4^{2}	1^{11}	2^{1}	33	43	37	5	3	8	o	tetraplegia	+	
36	6^{11}	1^{2}	1^{3}	31	35	31	3	3	6	g	diplegia	+	
36	8^{2}	0^{6}	1^{6}	34	31	30	6	1	5	g	diplegia	+	
37	4^{2}	0^{11}	2^{1}	43	43	21	0	11	11		diplegia		+
37	4^{2}	0^{11}	2^{1}	50	43	43	8	0	8		diplegia		+
37	6^{8}	2^{1}	2^{6}	43	43	21	0	9	9	g+o+p	diplegia		+

Unilateral adductor operations *First and secondary* Effect on the ipsilateral hip

PT	AGE years	OBSERVATION years		MIGRATION PERCENTAGE per cent			MIGRATION INDEX per cent/year		RESULTS per cent/year	ADDITIONAL OPERATIONS
	OP	PREOP	POSTOP	PRIM	PREOP	POSTOP	PREOP	POSTOP		
1	1^{1}	0^{3}	1^{2}	86	100	16	56	56	100	g
1	2^{3}	0^{9}	2^{8}	18	29	13	15	6	21	g
5	2^{1}	0^{9}	0^{8}	27	39	10	16	44	60	g+o
7	2^{7}	0^{9}	1	33	61	34	37	27	64	g
8	3^{9}	0^{8}	0^{11}	61	63	56	3	8	11	sem tend
8	4^{7}	0^{11}	1^{6}	63	56	28	8	19	11	o
9	3^{8}	1^{2}	0^{9}	41	30	24	9	8	1	o
11	5^{6}	3^{8}	2^{4}	30	72	29	1	18	30	g
16	9^{6}	1^{11}	1^{11}	35	44	41	5	2	7	g+h
16	12^{7}	0^{4}	0^{7}	38	37	30	3	12	9	g+p
24	5	0^{6}	0^{8}	52	50	4	4	1	8	g+o
27	2^{4}	0^{5}	1	60	64	56	10	6	16	g
30	5^{6}	1^{11}	1^{6}	38	58	44	10	9	19	g
31	12^{11}	1^{8}	2^{1}	55	61	69	4	4	0	g+p+r
32	4^{2}	1^{11}	2^{1}	33	43	37	5	3	8	o
33	6^{1}	2^{9}	2^{8}	33	45	16	4	11	15	g+o
34	5^{2}	0^{9}	0^{11}	47	52	2	7	33	40	g
34	6^{9}	0^{8}	0^{10}	37	39	28	3	13	16	g
36	6^{11}	1^{2}	1^{3}	31	35	31	3	3	6	g
36	8^{2}	0^{6}	1^{6}	34	31	0	6	1	5	g
37	6^{6}	1	2^{6}	43	43	1	0	9	9	g+o+p

Unilateral adductor operations *First and secondary* Effect on the contralateral hip

PT	AGE ye rs OP	OBSERVATION years PREOP	POSTOP	MIGRATION PERCENTAGE pe cent PRIM	PREOP	POSTOP	MIGRATION INDEX per ent/year PREOP	POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS
1	1	0^{3}	1^{3}	18	15	29	20	14	34	
1	2	0	2	18	16	22	3	2	5	
5	2	0^{9}	0^{8}	13	14	37	1	35	34	
7	2	0^{9}	1	7	6	5	1	1	0	g
8	3	0^{8}	0^{11}	50	31	30	29	1	28	
8	4	0^{3}	1	31	30	39	1	6	7	
9	3	1	0^{9}	39	33	33	5	0	5	
11	5	3^{4}	2^{4}	9	36	34	8	1	9	g
16	9^{4}	1	1	21	20	26	1	3	−4	g + h
16	12	0^{4}	0	25	24	24	5	0	3	
24	5	0^{8}	0^{8}	0	8	12	16	6	22	g
27	2^{9}	0	1^{4}	19	28	59	22	23	1	
30	5	1	1	6	15	26	4	9	13	
31	12	1	2^{3}	11	14	11	2	1	3	
32	4	1	2^{3}	14	23	21	5	1	6	
33	6	2	2^{9}	6	17	19	4	1	3	g
34	5	0^{9}	0^{3}	37	36	37	1	1	2	
34	6	0^{4}	0^{3}	22	18	14	6	5	1	
36	6	1	1^{3}	27	30	34	3	3	0	g
36	8	0^{8}	1^{8}	32	34	34	4	0	4	g + h
37	6	2	2^{3}	43	21	31	11	4	15	

Relation between migration percentage and passive abduction of one hip with straight legs

MIGRATION PERCENTAGE per en		PASSIVE ABDUCTION OF ONE HIP degrees 60	55	50	45	40	35	30	25	20	15	10	5	0	5
MP = 0	20					2	1	1	5	6	5				
0 < MP ≤ 33	114	1		4	10	10	2	20	26	24	11	3	2	1	
33 < MP ≤ 66	44			2	2		1	5	7	13	1	4	2	6	1
66 < MP ≤ 100	11								1	4	1	2		2	1

Relation between migration percentage and passive abduction of one hip with 90 flexion in the hip and knee

MIGRATION PERCENTAGE per en		PASSIVE ABDUCTION OF ONE HIP degrees 90	85	70	65	60	55	50	45	40	35	30	2	20	15	10	5	0
MP 0	20	1		1	3	3			5	2	2	3						
0 < MP ≤ 33	114		1	8	3	9	3	15	20	14	10	14	5	6	4	2		
33 < MP ≤ 66	44				1	5		5	7	9	3	3		6		2	3	
66 < MP ≤ 100	11							1		2		2		3		1		2

Secondary adductor operatıons

PT	AGE y rs OP	OBSERVATION y rs PREOP	POSTOP	MIGRATION PERCENTAGE pe ent PRIM	PREOP	POSTOP	MIGRATION INDEX pe ce t/ye PREOP	POSTOP	RESULTS pe cen /ye	ADDITIONAL OPERATIONS	DIAG NOSIS	LOW IQ	GIRL
2	3^{3}	1	0^{7}	42	47	41	5	10	15	g+o	tetraplegia	+	
2	3^{3}	1	0^{7}	36	50	21	14	50	64	g+o	tetraplegia	+	
2	4	0^{7}	1^{8}	47	41	25	10	11	1	g+semıtend	tetraplegia	+	
2	4	0^{7}	1^{6}	50	21	29	50	1	51	g+p	tetraplegia	+	
8	3^{9}	0^{8}	0^{11}	61	63	56	3	8	11	semıtend	tetraplegia	+	
8	4^{7}	0^{11}	1^{6}	63	56	28	8	19	11	o	tetraplegia	+	
9	3^{8}	1^{2}	0^{9}	41	30	24	9	8	1	o	dıplegia		+
10	4^{11}	2^{3}	2	46	40	42	2	1	5	g+o	paraplegia		
10	4^{11}	2^{3}	2	27	40	32	5	4	9	g+o	paraplegia		
15	11^{9}	3^{11}	2^{8}	29	25	21	1	2	1	o	dıplegia		
15	11^{9}	3^{11}	2^{8}	30	40	29	3	4	7	o	dıplegia		
16	12^{7}	0^{4}	0^{7}	38	37	30	3	12	9	g+p	tetraplegia	+	+
21	7^{8}	2^{6}	2^{7}	28	27	18	0	4	4	g+o	tetraplegia	+	+
21	7^{8}	2^{6}	2^{7}	4	9	18	2	3	1	g+o	tetraplegia	+	+
2	6^{2}	2	1^{8}	44	39	36	3	2	1	o	tetraplegia	+	+
22	6^{2}	2	1^{8}	56	60	49	2	7	9	o	tetraplegia	+	+
32	4^{2}	1^{11}	2^{1}	33	43	37	5	3	8	o	tetraplegia	+	
36	6^{11}	1^{2}	1^{3}	31	35	31	3	3	6	g	dıplegia	+	
36	8^{2}	0^{6}	1^{6}	34	31	30	6	1	5	g	dıplegia	+	
37	4^{2}	0^{11}	2^{1}	43	43	21	0	11	11		d plegia		+
37	4^{2}	0^{11}	2^{1}	50	43	43	8	0	8		dıplegia		+
37	6^{6}	2^{1}	2^{6}	43	43	21	0	9	9	g+o+p	d plegia		+

Unılateral adductor operatıons *Fırst and secondary* Effect on the ıpsılateral hıp

PT	AGE yea s OP	OBSERVATION years PREOP	POSTOP	MIGRATION PERCENTAGE per cent PRIM	PREOP	POSTOP	MIGRATION INDEX per cent/year PREOP	POSTOP	RESULTS per cent/year	ADDITIONAL OPERATIONS
1	1^{1}	0^{3}	1^{2}	86	100	16	56	56	100	g
1	2^{3}	0^{9}	2^{9}	18	29	13	15	6	21	g
5	2^{1}	0^{9}	0^{8}	27	39	10	16	44	60	g+o
7	2^{7}	0^{9}	1	33	61	34	37	27	64	g
8	3^{9}	0^{8}	0^{11}	61	63	56	3	8	11	semıt nd
8	4^{7}	0^{11}	1^{6}	63	56	28	8	19	11	o
9	3^{8}	1^{2}	0^{9}	41	30	24	9	8	1	o
11	5^{6}	3^{6}	2^{4}	30	7	29	12	18	30	g
16	9^{8}	1^{11}	1^{11}	35	44	41	5	2	7	g+h
16	12^{7}	0^{4}	0	38	37	30	3	12	9	g+p
24	5	0^{6}	0^{8}	5	50	4	4	12	8	g+o
27	2^{4}	0^{5}	1^{4}	60	64	56	10	6	16	g
30	5^{6}	1^{11}	1^{6}	38	58	44	10	9	19	g
31	12^{11}	1^{8}	2^{1}	55	61	69	4	4	0	g+p+r
32	4^{2}	1^{11}	2^{1}	33	43	37	5	3	8	o
33	6^{1}	2^{9}	2^{8}	33	45	16	4	11	15	g+o
34	5^{2}	0^{9}	0^{11}	47	52		7	33	40	g
34	6^{9}	0^{8}	0^{10}	37	39	28	3	13	16	g
36	6^{11}	1^{2}	1^{3}	31	35	31	3	3	6	g
36	8^{2}	0^{6}	1^{6}	34	31	30	6	1	5	g
37	6^{6}	2^{1}	2^{6}	43	43	21	0	9	9	g+o+p

Cozen L (1968) Some Evils of Fixed Abduction of the Hip Clinical Orthopaedics and Related Research 57 205 (61)

De Souza L J & Carroll N (1976) Ambulation of the Braced Myelomeningocele Patient Journal of Bone and Joint Surgery *58 A* 1112 (65)

Dobetti A & Manhood J (1968) A New Radiological Sign for Early Diagnosis of Congenital Hip Dysplasia Annales de Radiologie *11* 276 (20)

Ducharme F A (1967) Upper Femoral Resection in Paraplegia Indications Technique and Results Canadian Journal of Surgery *10* 318 (40)

Estere R (1960) Congenital Dislocation of the Hip Journal of Bone and Joint Surgery 42 B 253 (14)

Evans E B (1975) The Knee in Cerebral Palsy in Orthopaedic Aspects of Cerebral Palsy edited by R L Samilson Heinemann Ltd London page 173 (9)

Ferwell E Sakai D & Blatt Th (1978) The Effect of Hip Reduction in Patients with Myelomeningocele Journal of Bone and Joint Surgery *60 A* 169 (65)

Feldkamp M & Katthagen E W (1975) Ergebnisse operativer Korrekturen von Kniebeugekontrakturen bei zerebralparetischen Kindern Zeitschrift fur Orthopadie und Ihre Grenzgebiete *113* 181 (9)

Feldkamp M (1976) Asymmetrische Huftfehlstellung bei Kindern mit infantiler Zerebralparesen Zeitschrift fur Orthopadie und Ihre Grenzgebiete *114* 317 (8)

Fettweis E (1971) Zur Prophylaxe des kindlichen Huftluxationsleidens Zeitschrift fur Orthopadie und Ihre Grenzgebiete *109* 905 (6)

Fettweis E (1973) Das Huftluxationsleiden bei in Beckenendlage geborenen Kindern Zur Pathogenese und Bedeutung fur das Luxationsproblem Zeitschrift fur Orthopadie und Ihre Grenzgebiete *111* 168 (7)

Fredensborg N (1975) Congenital Dislocation of the Hip Thesis Malmo (14 18 21)

Fredensborg N (1976) Observations in Children with Congenital Dislocation of the Hip Acta Orthopaedica Scandinavica *47* 175 (65)

Freeman M A R Swanson S A V & Todd R C (1973) Total Replacement of the Knee Using the Freeman Swanson Knee Prosthesis Clinical Orthopaedics and Related Research *94* 153 (27)

Friedenberg Z B (1963) Protrusio Acetabuli in Childhood Journal of Bone and Joint Surgery *45-A* 373 (23)

Fujiwara M Basmajian J V & Strom C H (1974) Electromyographic Study of Hip Dislocation in Cerebral Palsy American Journal of Physical Medicine *53* 171 (9 40)

Fuldford G E & Brown J K (1976) Position as a Cause of Deformity in Children with Cerebral Palsy Developmental Medicine and Child Neurology *18* 305 (8)

Gaugele K (1906) Über die Kombination der angeborenen Huftgelenkverrenkung mit Littleschen Krankheit Zeitschrift fur orthopadische Chirurgie *XVII* 342 (7 29)

Glauber A Vizkelety T & Szepesi K (1967) Die Rolle des im Pathomechanismus der sogenanten angeborenen Huftluxation Archiv fur orthopadische und Unfall Chirurgie *62* 291 (6)

Gustafsson P O (1971) Höftledsdysplasi hos hund Thesis Stockholm (65)

Hagberg B Hirsch C & Steen M (1964) Resection of the Obturator Nerve in the Treatment of Adductor Spasticity in Cerebral Palsy Acta *Orthopaedica* Scandinavica *34* 258 (9 42)

Harris L E Lipscomb P R & Hodgson J R (1960) Hilgenreiner Measurements of the Hip Roentgenograms in 247 Normal Infants 6 to 7 Months of Age Follow up of Deviations from Normal Journal of Pediatrics 56 478 (12 13 25)

Harris N H Lloyd Roberts G C & Gallien R (1975) Acetabular Development in Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *57 B* 46 (13 15)

Hart V L (195) Congenital Dysplasia of the Hip Joint and Sequelae In the Newborn and Early Postnatal Life Charles C Thomas Springfield U S A (15 20 65)

Heyman C H & Herndon C (1950) Legg Perthes Disease A Method for the Measurement of the Roentgenographic Result Journal of Bone and Joint Surgery *32 A* 767 (15 16)

Hilgenreiner H (19 5) Medizinische Klinik *21* 1585 (12 13)

Holt K S (1965) Assessment of Cerebral Palsy Lloyd Luke Ltd London (59)

Literature

(The numbers in brackets refer to the pages in the present work in which the authors are quoted)

Albert E (1952) Dysplasie und Huftarthrose unter besonderer Berucksichtigung der Subluxation Zeitschrift fur Orthopadie und Ihre Grenzgebiete *82* 23 (23)

Andren L & von Rosen S (1958) The Diagnosis of Dislocation of the Hip in Newborns and the Primary Results of Immediate Treatment Acta Radiologica *49* 89 (13)

Anthonsen W (1966) Treatment of Hip Flexion Contracture in Cerebral Palsy Patients Acta Ortho paedica Scandinavica *37* 387 (43)

Anthonsen W & Reimers J (1970) A New Adjustable Iron Cross Bar to be Used in Plaster Casts Acta Orthopaedica Scandinavica *41* 495 (43)

Baacke M & Tonnis D (1974) Erworbene Huftgelenkdysplasia nach Versteifung der Gegenseite in Abduktion Zeitschrift fur Orthopadie und Ihre Grenzgebiete *112* 78 (25 55 61)

Baker L D Dodelin R & Bassett F H (1962) Pathological Changes in the Hip in Cerebral Palsy Incidence Pathogenesis and Treatment Journal of Bone and Joint Surgery *44-A* 1331 (9 12 25 31)

Ball F & Kommenda K (1968) Sources of Error in the Roentgen Evaluation of the Hip in Infancy Annales de Radiologie *11* 298 (13)

Banks H H & Green W T (1960) Adductor Myotomy for the Correction of Adduction Contracture of the Hip in Cerebral Palsy Journal of Bone and Joint Surgery *42-A* 111 (8 29 31)

Barry C (1969) Some Mechanisms Leading to Disorders of the Hip in Cerebral Palsy Journal of the Irish Medical Association *62* 51 (9)

Baumann J U (1970) Operative Behandlung der infantilen Zerebralparesen Georg Thieme Stutt gart (43)

Bellyei A Barta O & Kranicz J (1975) Die Auswertung der Behandlungsergebnisse der Perthes schen Krankheit Beitrage zur Orthopadie und Traumatologie *22* 618 (16)

Bibliographie Generale (1963) Acta Orthopaedica Belgica *29* 485 (9)

Bibliographie (1967) Revue de Chirurgie Orthopedique *53* 787 (9)

Bjerkreim I (1974a) Congenital Dislocation of the Hip Joint in Norway Acta Orthopaedica Scandi navica Suppl *157* (15 25 65)

Bjerkreim I (1974b) Secondary Dysplasia and Osteoarthrosis of the Hip Joint in Functional and Fixed Obliquity of the Pelvis Acta Orthopaedica Scandinavica *45* 873 (23 55 61)

Bohr H Baadsgaard K & Sager Ph (1965) The Vascular Supply to the Femoral Head Following Dislocation of the Hip Joint Acta Orthopaedica Scandinavica *XXXV* 264 (13)

Bragard K (1925) Uber die Wirkungen der Adduktoren auf das obere Femurende Verhandlungen der Deutschen Orthopadischen Gesellschaft 20 Kongress Ferdinand Enke Stuttgart (6)

Brooks M & Wardle E N (1962) Muscle Action and the Shape of the Femur Journal of Bone and Joint Surgery *44-B* 398 (6)

Busse J Gasteiger W & Tonnis D (1972) Eine neue Methode zur rontgenologischen Beurteilung eines Huftgelenkes – Der Huftwert Archiv fur Orthopadische und Unfall Chirurgie *72* 1 (21 23)

Caffey J Ames R Silverman W A Ryder Ch T & Hough G (1956) Contradiction of the Con genital Dysplasia – Predislocation Hypothesis of Congenital Dislocation of the Hip through a Study of the Normal Variation in Acetabular Angles at Successive Periods in Infancy Pediatrics *17* 632 (12)

Cardinet G H Guffy M M & Wallace L J (1974) Canine Hip Dysplasia Effects of Pectineal Myectomy on the Coxofemoral Joints of Greyhound and German Shepherd Dogs Journal of the American Veterinary Medical Association *165* 529 (7)

Carroll N C & Sharrard W J W (1972) Long Term Follow up of Posterior Iliopsoas Transplanta tion for Paralytic Dislocation of the Hip Journal of Bone and Joint Surgery *54 A* 551 (5)

Collert S (1974) Results after Intertrochanteric Osteotomy in Osteoarthritis of the Hip Thesis Stock holm page 76 (27)

Massie W K & Howorth M B (1950) Congenital Dislocation of the Hip Part I Method of Grading Results Journal of Bone and Joint Surgery *32-A* 519 (12 14 15 21 24 26)

Matheus A S Jones M H & Sperling S C (1953) Hip Derangements seen in Cerebral Palsied Children American Journal of Physical Medicine *32* 213 (8 17)

Matsoukas J Papadimitriou D & Euthymiou C (1969) Etude Histologique des Muscle Pelvi femoraux chez les enfants porteurs d une luxation congenitale de la hanche Constatations histopatho logiques originales Helvetia Paediatrica Acta *24* 201 (7)

Mau H (1954) Die Huftgelenkveranderung bei spastischen Lahmungen Zeitschrift fur Orthopadie und Ihre Grenzgebiete *84* 407 (8 29)

McKibbin B (1970) Anatomical Factors in the Stability of the Hip Joint in the Newborn Journal of Bone and Joint Surgery *52-B* 148 (5 65)

McKibbin B (1973) The Use of Splintage in the Management of Paralytic Dislocation of the Hip in Spina Bifida Cystica Journal of Bone and Joint Surgery *55-B* 163 (5)

Medbo I U (1961) Early Diagnosis and Treatment of Hip Joint Dysplasia Acta Orthopaedica Scandinavica *31* 28? (15 16 20 25)

Medbo I U (1965) Follow up Study of Hip Joint Dysplasia Treated from the Newborn Stage Acta Orthopaedica Scandinavica *35* 338 (14 21)

Menelaus M B (1969) Dislocation and Deformity of the Hip in Children with Spina Bifida Cystica Journal of Bone and Joint Surgery *51-B* 238 (5)

Merchant A C (1965) Hip Abductor Muscle Force Journal of Bone and Joint Surgery *47-B* 462 (6 61)

Mezzari A (1928) Sul valure del segno di Shenton per la diagnosi radiografica della lussatione congenita dell anca nella prima infanzia La Radiologia Medica *15* 13 (17)

Michele A A (196?) Iliopsoas Development of Anomalies in Man Charles C Thomas Springfield U S A (8)

Michelsson J E & Langenskiold A (1972) Dislocation or Subluxation of the Hip Regular Sequels of Immobilization of the Knee in Extension in Young Rabbits Journal of Bone and Joint Surgery *54 A* 1177 (7 47)

Morville P (1933) The Incongruous Hip Acta Orthopaedica Scandinavica *II* 133 (23)

Muller M E (1956) Ischiometrie Radiologique Revue de Chirurgie et Reparatrice de L appareil *42* 124 (14)

O Malley A G (1965) Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *47-B* 188 (6)

Ombredanne L (1932) Precis clinique et operatoire de Chirurgie infantile Troisieme Ed Masson et Cie Paris page 1113 (16 20)

Perkins G (19 8) S gns by Which to Diagnose Congenital Dislocation of the Hip Lancet *I* 648 (16 20)

Phelps W M (1959) Prevention of Acquired Dislocation of the Hip in Cerebral Palsy Journal of Bone and Joint Surgery *41 A* 440 (8 29)

Plum P (1961) The Place of Orthopaedic Surgery in the Treatment of Cerebral Palsy Acta Chirurgica Scandinavica Suppl *283* 303 (8)

Plum P (1975) Personal Communication (47)

Pollock G A & Sharrard W J W (1958) Recent Advances in Cerebral Palsy 1st Ed Churchill London page 286 (8 29 40)

Putti V (1932) Analisi della triade radiosintomatica degli stati di prelussazione La Chirurgia degli Organi di Movimento *XVII* 453 (16 20)

Putti V (1937) Die Anatomie der angeborenen Huftverrenkung Ferdinand Enke Stuttgart (14 15)

Rang M (1969) The Growth Plate and Its Disorders 1st Ed Livingstone Ltd Edinburgh page 145 (6)

Rang M (1975) Personal Communication (17)

Ravell A (1953) Röntgenzeichen und Messmethoden zur Erkennung der angeborenen Dysplasie der Hufte Radiologia Austriaca *VI* 177 (14)

Reimers J (1971) Den ortopædkirurgiske behandling af C P Hofteleddet (Danish) Tidsskrift for Cerebral Parese *20* 57 (15)

Hooper J C & Jones E W (1971) Primary Protrusion of the Acetabulum Journal of Bone and Joint Surgery *53-A* 23 (23)

Ingram A J & Farrar E L (1955) Congenital Dysplasia of the Hip Recognition and Treatment Pediatric Clinics of North America November 1081 (20)

Ingram A J (1971) Cerebral Palsy in Campbell s Operative Orthopaedics edited by A H Crenshaw 5th Ed C V Mosby Co Saint Louis U S A page 1685 (31)

Inman V T (1947) Functional Aspects of the Abductor Muscles of the Hip Journal of Bone and Joint Surgery *29* 607 (6)

Janovec M (1973) Studie uber den Einfluss der Lage des Sauglingsbeckens auf das Röntgenbild Beitrage zur Orthopadie und Traumatologie *9* 445 (13)

Jones G B (1962) Paralytic Dislocation of the Hip Journal of Bone and Joint Surgery *44 B* 573 (8 29 40)

Keats S (1957) Combined Adductor Gracilis Tenotomy and Selective Obturator Nerve Resection for the Correction of Adductor Deformity in the Hip in Children with Cerebral Palsy Journal of Bone and Joint Surgery *39 A* 1087 (8)

Kemp H S & Boldero J L (1966) Radiological Changes in Perthes Disease British Journal of Radiology *39* 744 (13)

Kleinberg S & Lieberman H S (1936) The Acetabular Index in Infants in Relation to Congenital Dislocation of the Hip Archives of Surgery *34* 1019 (12)

Klopfer F (1950) Zur Problematik der Sofortbehandlung bei angeborener Huftgelenkdysplasie Zeitschrift fur Orthopadie und Ihre Grenzgebiete *79* 1 (8 29)

Kunne B (1914) Paralytische und spastische Huftluxation Archiv fur Orthopadie Mechanotherapie und Unfall Chirurgie *XIII* 111 (8)

Lamb D W & Pollock G A (1962) Hip Deformities in Cerebral Palsy and Their Treatment Developmental Medicine and Child Neurology *4* 488 (9 29)

Lange F (1921) Die Entstehung der Coxa Valga durch Muskelzug (adduktoren coxa valga) Zeitsch r i f t
fur orthopadische Chirurgie *4* 147 (8)

Langenskiold A Sarpio O & Michelsson J E (1962) Experimental Dislocation of the Hip in Rabbit Journal of Bone and Joint Surgery *44-B* 209 (13)

Laurensen R D (1959) The Acetabular Index A Critical Review Journal of Bone and Joint Surgery *41-B* 702 (13)

Le Cœur P Cartier L & Mallet (1959) Luxations chez les Paralytiques Revue de Chirurgie Orthopedique et Reparatrice de L appareil *45* 39 (8)

Leffmann R (1959) Congenital Dysplasia of the Hip With Special Reference to Congenital Subluxation or Pre luxation Journal of Bone and Joint Surgery *41-B* 689 (62)

Lequesne M (1963) Coxométrie Mesure des angles fondamentaux de la hanche radiographique de l adulte par un rapporteur combine Revue du Rhumatisme *30* 479 (14)

Lewis F R Samilson R R & Lucas D B (1964) Femoral Torsion and Coxa Valga in Cerebral Palsy Developmental Medicine and Child Neurology *6* 591 (9)

London J T & Nichols O (1975) Paralytic Dislocation of the Hip in Myelodysplasia The Role of the Adductor Transfer Journal of Bone and Joint Surgery *57 A* 501 (6)

Lorenz A (1897) Uber die Chirurgische Behandlung der angeborenen spastische Gliederstarre Wiener klinische Rundschau page 21 25 and 27 (7)

Lude L & Taillard W (1964) Le developpement de la congruence articulaire de la hanche chez l enfant Revue de Chirurgie Orthopédique et Reparatrice de L appareil *50* 757 (14)

Ludloff K (1902) Zur Pathogenese und Therapie der angeborenen Huftgelenksluxation Klinischen Jahrbuch 10 Gustav Fischer Jena (7 15 29)

Lusted L B & Keats Th E (1967) Atlas of Roentgenographic Measurement II ed Year Book Medical Publishers Inc U S A (12)

MacKenzie I G Seddon H J & Trevor D (1960) Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *42 B* 689 (14 16 25)

Martin H E (1951) Geometrical Anatomical Factors and Their Significance in the Early X Ray Diagnosis of the Hip Joint Disease in Children Radiology *56* 842 (13 15 16 20)

Massie W K & Howorth M B (1950) Congenital Dislocation of the Hip Part I Method of Grading Results Journal of Bone and Joint Surgery *32–A* 519 (12 14 15 21 24 26)

Mathews A S Jones M H & Sperling S C (1953) Hip Derangements seen in Cerebral Palsied Children American Journal of Physical Medicine *32* 213 (8 17)

Matsoukas J Papadimitriou D & Euthymiou C (1969) Etude Histologique des Muscle Pelvi femoraux chez les enfants porteurs d une luxation congenitale de la hanche Constatations histopathologiques originales Helvetia Paediatrica Acta *24* 201 (7)

Mau H (1954) Die Huftgelenkveranderung bei spastischen Lahmungen Zeitschrift fur Orthopadie und Ihre Grenzgebiete *84* 407 (8 29)

McKibbin B (1970) Anatomical Factors in the Stability of the Hip Joint in the Newborn Journal of Bone and Joint Surgery *52 B* 148 (5 65)

McKibbin B (1973) The Use of Splintage in the Management of Paralytic Dislocation of the Hip in Spina Bifida Cystica Journal of Bone and Joint Surgery *55–B* 163 (5)

Medbo I U (1961) Early Diagnosis and Treatment of Hip Joint Dysplasia Acta Orthopaedica Scandinavica *31* 282 (15 16 20 25)

Medbo I U (1965) Follow up Study of Hip Joint Dysplasia Treated from the Newborn Stage Acta Orthopaedica Scandinavica *35* 338 (14 21)

Menelaus M B (1969) Dislocation and Deformity of the Hip in Children with Spina Bifida Cystica Journal of Bone and Joint Surgery *51–B* 238 (5)

Merchant A C (1965) Hip Abductor Muscle Force Journal of Bone and Joint Surgery *47 B* 462 (6 61)

Mezzari A (1928) Sul valure del segno di Shenton per la diagnosi radiografica della lussatione congenita dell anca nella prima infanzia La Radiologia Medica *15* 13 (17)

Michele A A (1962) Iliopsoas Development of Anomalies in Man Charles C Thomas Springfield U S A (8)

Michelsson J E & Langenskiold A (1972) Dislocation or Subluxation of the Hip *Regular Sequels* of Immobilization of the Knee in Extension in Young Rabbits Journal of Bone and Joint Surgery *54 A* 1177 (7 47)

Morville P (1933) The Incongruous Hip Acta Orthopaedica Scandinavica *IV* 133 (23)

Muller M E (1956) Ischiometrie Radiologique Revue de Chirurgie et Reparatrice de L appareil *42* 124 (14)

O Malley A G (1965) Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *47–B* 188 (6)

Ombredanne L (1932) Précis clinique et operatoire de Chirurgie infantile Troisieme Ed Masson et Cie Paris page 1113 (16 20)

Perkins G (19_8) Signs by Which to Diagnose Congenital Dislocation of the Hip Lancet *I* 648 (16 20)

Phelps W M (1959) Prevention of Acquired Dislocation of the Hip in Cerebral Palsy Journal of Bone and Joint Surgery *41 A* 440 (8 29)

Plum P (1961) The Place of Orthopaedic Surgery in the Treatment of Cerebral Palsy Acta Chirurgica Scandinavica Suppl *283* 303 (8)

Plum P (1975) Personal Communication (47)

Pollock G A & Sharrard W J W (1958) Recent Ad ances in Cerebral Palsy 1st Ed Churchill London page 286 (8 29 40)

Putti V (193) Analisi della triade radiosintomatica degli stati di prelussazione La Chirurgia degli Organi di Movimento *XVII* 453 (16 20)

Putti V (1937) D e Anatomie der angeborenen Huftverrenkung Ferdinand Enke Stuttgart (14 15)

Rang M (1969) The Growth Plate and Its Disorders 1st Ed Livingstone Ltd *Ed* nburgh page 145 (6)

Rang M (1975) Personal Communication (17)

Ravelli A (1953) Röntgenzeichen und Messmethoden zur Erkennung der angeborenen Dysplasie der Hufte Radiologia Austriaca *VI* 177 (14)

Reime s J (1971) Den ortopædkirurgiske behandling af C P Hofteleddet (Danish) Tidsskrift for Cerebral Parese *0* 57 (15)

Hooper J C & Jones E W (1971) Primary Protrusion of the Acetabulum Journal of Bone and Joint Surgery *53-A* 23 (23)

Ingram A J & Farrar E L (1955) Congenital Dysplasia of the Hip Recognition and Treatment Pe diatric Clinics of North America November 1081 (20)

Ingram A J (1971) Cerebral Palsy in Campbell s Operative Orthopaedics edited by A H Crenshaw 5th Ed C V *Mosby Co Saint Louis U S A* page *1685* (31)

Inman V T (1947) Functional Aspects of the Abductor Muscles of the Hip Journal of Bone and Joint Surgery *29* 607 (6)

Janotec M (1973) Studie uber den Einfluss der Lage des Sauglingsbeckens auf das Rontgenbild Bei trage zur Orthopadie und Traumatologie *9* 445 (13)

Jones G B (1962) Paralytic Dislocation of the Hip Journal of Bone and Joint Surgery *44-B* 573 (8 29 40)

Keats S (1957) Combined Adductor Gracilis Tenotomy and Selective Obturator Nerve Resection for the Correction of Adductor Deformity in the Hip in Children with Cerebral Palsy Journal of Bone and Joint Surgery *39-A* 1087 (8)

Kemp H S & Boldero J L (1966) Radiological Changes in Perthes Disease British Journal of Ra diology *39* 744 (13)

Kleinberg S & Lieberman H S (1936) The Acetabular Index in Infants in Relation to Congenital Dislocation of the Hip Archives of Surgery *34* 1049 (12)

Klopfer F (1950) Zur Problematik der Sofortbehandlung bei angeborener Huftgelenkdysplasie Zeit schrift fur Orthopadie und Ihre Grenzgebiete *79* 1 *(8 29)*

Kunne B (1914) Paralytische und spastische Huftluxation Archiv fur Orthopadie Mechanotherapie und Unfall Chirurgie *XIII* 111 (8)

Lamb D W & Pollock G A (1962) Hip Deformities in Cerebral Palsy and Their Treatment *Developmental Medicine and Child Neurology 4 488 (9 29)*

Lange F (1921) Die Entstehung der Coxa Valga durch Muskelzug (adduktoren coxa valga) Zeitsch r i f t
fur orthopadische Chirurgie *4* 147 (8)

Langenskiold A Sarpio O & Michelsson J E (1962) Experimental Dislocation of the Hip in Rab bit Journal of Bone and Joint Surgery *44-B* 209 (13)

Laurensen R D (1959) The Acetabular Index A Critical Review Journal of Bone and Joint Surgery *41-B* 702 (13)

Le Cœur P Cartier L & Mallet (1959) Luxations chez les Paralytiques Revue de Chirurgie Ortho pedique et Reparatrice de L appareil *45* 39 (8)

Leffmann R (1959) Congenital Dysplasia of the Hip With Special Reference to Congenital Subluxa tion or Pre luxation Journal of Bone and Joint Surgery *41-B* 689 (62)

Lequesne M (1963) Coxometrie Mesure des angles fondamentaux de la hanche radiographique de l adulte par un rapporteur combine Revue du Rhumatisme *30* 479 (14)

Lewis F R Samilson R R & Lucas D B (1964) Femoral Torsion and Coxa Valga in Cerebral Pal sy *Developmental Medicine and Child Neurology 6* 591 (9)

London J T & Nichols O (1975) Paralytic Dislocation of the Hip in Myelodysplasia The Role of the Adductor Transfer Journal of Bone and Joint Surgery *57-A* 501 (6)

Lorenz A (1897) Uber die Chirurgische Behandlung der angeborenen spastische Gliederstarre Wiener klinische Rundschau page 21 25 *and* 27 (7)

Lude L & Taillard W (1964) Le developpement de la congruence articulaire de la hanche chez l enfant Revue de Chirurgie Orthopedique et Reparatrice de L appareil *50* 757 (14)

Ludloff K (1902) Zur Pathogenese und Therapie der angeborenen Huftgelenksluxation Klinischen Jahrbuch 10 Gustav Fischer Jena *(7 15 29)*

Lusted L B & Keats Th E (1967) Atlas of Roentgenographic Measurement II ed Year Book Medi cal Publishers Inc U S A (12)

MacKenzie I G Seddon H J & Trevor D (1960) Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *42-B 689 (14 16 25)*

Martin H E (1951) Geometrical Anatomical Factors and Their Significance in the Early X Ray Diagnosis of the Hip Joint Disease in Children Radiology *56* 842 (13 15 16 20)

Smith W S Coleman C R Olix M & Slager R F (1963) Etiology of Congenital Dislocation of the Hip An Experimental Approach to the Problem Using Young Dogs Journal of Bone and Joint Surgery *45 A* 491 (13)

Smith W S Badgley C F Orwig J B & Harper J M (1968) Correlation of Postreduction Roentgenograms and Thirty One Year Follow Up in Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *50 A* 1081 (16 23 25)

Snyder Ch R (1975) Legg Perthes Disease in the Young Hip — Does It Necessarily Do Well Journal of Bone and Joint Surgery *57 A* 751 (14 15 16 20 25)

Tanabe G Kotakemori K Miyake Y & Mohri M (1972) Early Diagnosis of Congenital Dislocation of the Hip Acta Orthopaedica Scandinavica *43* 511 (65)

Trevor D Johns D L & Fixen J A (1975) Acetabuloplasty in the Treatment of Congenital Dislocation of the Hip Journal of Bone and Joint Surgery *57-B* 167 (13 15 16)

Tonnis D (1969) Elektromyographische und histologische Untersuchungen zur Frage der *Entstehung* der angeborenen Huftluxation Zeitschrift fur Orthopadie und Ihre Grenzgebiete *105* 527 (7)

Watson Jones Sir R (1926) Spontaneus Dislocation of the Hip British Journal of Surgery *14* 36 (8 31 40)

Weber H (1911) Über die Spastische Huftluxation und die Veranderung des Huftgelenkes bei spastischen Zustanden der unteren Extremitaten Muencher Medizinische Wochenschrift *58* 794 (8 13 40)

Weickert H (1975) Fortschritte in der Diagnostik und Behandlung der Luxationshufte Padiatrie und Grenzgebiete *14* 63 (65)

Whittick W G (1974) Canine Orthopedics Lea & Febiger Philadelphia U S A (60 65)

Wiberg G (1939) Studies on Dysplastic Acetabula and Congenital Subluxation of the Hip Joint With Special Reference to the Complication of Osteoarthritis Acta Chirurgica Scandinavica Suppl *58* (13 21 23 25)

Wiberg G (1975) Personal Communication (15)

Wollenberg G A (1908) Little sche Krankheit und Huftluxation Berliner Klinische Wochenschrift *45* 1174 (8 29)

Wolff (189) Das Gesetz des Transformation der Knochen Berlin Hirschwald

Wolff J R & Tonnis D (1970) Elektronenmikroskopische Untersuchungen der Muskulatur bei angeborenen Klumpfuss und angeborener Huftluxation Archiv fur orthopadische und Unfall Chirurgie *68* 95 (7)

Vulpius O & Stoffel A (1913) Orthopadische Operationslehre Ferdinand Enke Stuttgart page 307 (42)

Ziernaviczky J & Turk C (1974) Uber ein neues Röntgenzeichen in der Fruhdiagnostik der kongenitalen Huftdysplasie Zeitschrift fur Orthopadie *und Ihre* Grenzgebiete *112* 460 (16 25)

Zweymuller K & Wicke B (1973) Zur Lateralisation des Oberschenkelkopfes beim M Perthes Archiv fur orthopadische und Unfall Chirurgie *75* 239 (16)

Reimers J (1973a) Paresis Cerebralis Ortopæd Kirurgisk Terapi (Danish) in Nordisk Lærebog i Pæ diatri edited by B Friis Hansen 7th Ed Munksgaard Copenhagen page 480 (15)
Reimers J (1973b) Static and Dynamic Problems in Spastic Cerebral Palsy Journal of Bone and Joint Surgery *55-B* 822 (5)
Reimers J (1974) Contracture of the Hamstrings in Spastic Cerebral Palsy Journal of Bone and Joint Surgery *56-B* 102 (44 55)
Riser W H (1974) Canine Hip Dysplasia Cause and Control Journal of the American Veterinary Medical Association *165* 360 (65)
Rubens Duval A Vilhaumey J & Aristoff H (1963) Technique de Mensuration de la Statique Pelvi Femorale dans les Dysplasies et Arthroses Coxo Femorales Revue du Rhumatisme *30* 275 (16)
Rueda J & Carroll N C (1972) Hip Instability in Patients with Myelomeningocele Journal of Bone and Joint Surgery *54-B* 422 (5)
Salter R B (1967) Congenital Dislocation of the Hip in Modern Trends in Orthopaedics edited by W D Graham *5* 140 (65)
Salter R B Kostuik J & Dallas S (1969) Avascular Necrosis of the Femoral Head as a Complica tion of Treatment for Congenital Dislocation of the Hip in Young Children A Clinical and Experi mental Investigation Canadian Journal of Surgery *12* 44 (57)
Salter R B (1970) Textbook of Disorders and Injuries of the Musculoskeletal System Williams & Wil kins Co Baltimore (25)
Samilson R L Carson J J James P & Raney F L (1967) Results and Complications of Adductor Tenotomy and Obturator Neurectomy in Cerebral Palsy Clinical Orthopaedics and Related Re search *54* 61 (9 31 33 39 54 55)
Samilson R L Tsou P Aamoth G & Green W M (1972) Dislocation and Subluxation of the Hip in Cerebral Palsy Journal of Bone and Joint Surgery *54-A* 863 (8 9 25 31 40 55 64)
Scheibel O (1928) Om Behandlingen af den spastiske Spidsfod (Danish) Hospitalstidende *71* 1 (7)
Schiller M G & Axer A (1972) Legg Calve Perthes Syndrome A Critical Analysis of Roentgeno graphic Measurements Clinical Orthopaedics and Related Research *86* 34 (16)
Severin E (1941) Contribution to the Knowledge of Congenital Dislocation of the Hip Late Results of Closed Reduction and Arthrographic Studies of Recent Cases Acta Chirurgica Scandinavica *LXXXIV* Suppl 63 (12 13 14 21 25)
Sharp I K (1961) Acetabular Dysplasia The Acetabular Angle Journal of Bone and Joint Surgery *43-B* 268 (13 14 15 21 25)
Sharrard W J W (1964) The Segmental Innervation of the Lower Limb in Man Annals of the Royal College of Surgeons of England *35* 106 (5)
Sharrard W J W (1967) Paralytic Deformity in the Lower Limb Journal of Bone and Joint Surgery *49-B* 731 (60)
Sharrard W J W (1969) The Orthopaedic Surgery of Cerebral Palsy and Spina Bifida in Recent Ad vances in Orthopaedics edited by A G Apley Churchill Ltd London page 265 (15)
Sharrard W J W Allen J M H Heaney S H & Prendiville G R G (1975) Surgical Prophylaxis of Subluxation and Dislocation of the Hip in Cerebral Palsy Journal of Bone and Joint Surgery *57-B* 160 (9 13 18 20 25 31 33 34 35 39 40 62 64 69 74)
Sharrard W J W (1975a) The Hip in Cerebral Palsy in Orthopaedic Aspects of Cerebral Palsy edited by R L Samilson Heinemann Ltd London page 145 (60)
Sharrard W J W (1975b) The Orthopaedic Management of Spina Bifida Acta Orthopaedica Scan dinavica *46* 356 (5)
Sijbrandij S (1965 Dislocation of the Hip in Young Rats Produced Experimentally by Prolonged Ex tension Journal of Bone and Joint Surgery *47-B* 792 (6 13)
Silfverskiold N (1924) Orthopadische Studie uber Hemiplegia spastica Infantilis Acta Chirurgica Scandinavica Suppl *I* (7)
Silver C M Simon S D & Litchman H M (1966) The Use and Abuse of Obturator Neurectomy Developmental Medicine and Child Neurology *8* 203 (42)
Smith E T (1969) Hip Dislocation in Cerebral Palsy Developmental Medicine and Child Neurology *11* 291 (9)

Subject index

LARS-ÅKE BROSTRÖM

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From the Department of Orthopaedic Surgery
Karolinska Hospital Stockholm Sweden

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BY

LARS ÅKE BROSTRÖM

MUNKSGAARD COPENHAGEN

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and just therein lies his dignity

Immanuel Kant

Translated by Catherine Sundstrom

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The present work is based on the following papers which will be referred to by their Roman numerals

I Brostrom L Å Harris M Simon M Cooperman D Nilsonne U The effect of biopsy on survival of patients with osteosarcoma J Bone Jt Surg. 61B 209–212 1979

II Brostrom L Å Aparisi T Ingimarsson S Lagergren C Nilsonne U Strander H Soderberg G Can historical controls be used in current clinical trials in osteo sarcoma? Analysis of prognostic factors in a historical and a contemporary group Int J Rad Oncol Biol Phys (In press)

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IV Brostrom L Å Ingimarsson S Strander H Eklund G Correlation between prognostic factors and blood variables in osteosarcoma Acta med scand (In press)

V Brostrom L Å Adamson U Filipsson R Hall K Longitudinal growth and dental development in osteosarcoma patients Acta Orthop Scand Accepted for publication

VI Adamson U Brostrom L Å. Efendic S Hall K Glucose tolerance growth hormone and somatomedin levels in osteosarcoma patients Acta endocr (Kbh) Accepted for publication

CONTENTS

CHAPTER I – INTRODUCTION

History

Primary malignant bone tumours account for less than 1 % of all malignant tumours in man in all ages[26,131] Osteosarcoma occurs predominantly during the first three decades of life and is the most common primary malignant bone tumour in this age group[14,26,61,67,77,79,86,104,116,118,131,147]

Smith and Dawson[123] reported in 1924 that evidence has been found dating the occurrence of primary bone tumours as far back as the fifth Egyptian dynasty The term osteosarcoma was used by Boyer[6] as early as 1807 and a first attempt at classifying bone tumours into malignant and benign forms was presented by Nelaton[92] in 1860 More systematic classifications have later been published by Codman[20] in 1925 Scarff[117] in 1937 Ewing[39] in 1939 and Cade[13] in 1947 and more recently by Lichtenstein[79] in 1952 Dahlin[26] in 1957 and Jaffe[61] in 1958

The term osteogeni sarcoma is encountered early in the literature without any clear distinction from chondrosarcoma and fibrosarcoma which were often included in this concept Some authors have used the term osteogenic sarcoma as a collective designation for different malignant primary tumours of bone[81,82,83] whereras others use the term as synonymous to osteosarcoma[28,61,79,86,94,97,136] In recent years the term osteogenic sarcoma has been virtually ousted by osteosarcoma to designate the specific primary malignant bone tumour which histopathologically is characterized by osteoid producing malignant bone cells[28,76,116,136] An annual incidence of 2 cases per million inhabitants has been reported[74,103]

Pathology

It is often difficult to make a diagnosis of osteosarcoma on the basis of the histopathological findings especially as the bone tissue contains cells of many different types and varying stages of maturity It has been suggested that the tumour cells originate from immature osteogenic mesenchymal cells in combination with often completely anaplastic connective tissue cells of spindle shaped type[14,28,29,36,80,82] Giant cells of both malignant and benign type are frequently seen but an absolute condition for a diagnosis of osteosarcoma is the presence of osteoid[26,28,61,79,81,83,136]

Tumours designated as osteosarcoma may be further distinguished according to the predominant cell type into an osteoblastic chondroblastic or fibroblastic variety In large series such as those presented by Dahlin[26,29] about 50 % of the tumours are of the osteoblastic type while the chondroblastic and fibroblastic types account for about 25 % each Different portions of the solid tumour may present an entirely different histological picture which makes it difficult to differentiate osteosarcoma from chondrosarcoma or fibrosarcoma and sometimes also from wholly benign conditions like an-urysmal bone cyst fibrous dysplasia or chronic osteomyelitis[26,61,79]

The degree of malignancy can be assessed by examining the degree of differentiation of the tumour cells as reflected by nuclear appearance and mitotic frequency Broders et al.[9] have described such a grading system based on a four-grade scale in which grade IV represents the least differentiated tumour type Another malignancy grading system based on mitotic frequency has been presented by Price[101]

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Diagnosis

The diagnosis of osteosarcoma is based on both clinical, radiological and histopathological findings Somewhat varying meanings have been attached to the term classical osteosarcoma in the literature, but in the present work it is used to define intraosseous osteosarcoma in young individuals usually under 30 years of age, with a peak incidence during the second decade of life often coinciding with the pubertal growth spurt The most common site of the tumour is the metaphyseal region of the long bones and a predominance has been noted among males The radiological findings often present a typical pattern with destructive tumour growth through the cortex Frequent findings are osteolysis and osteosclerosis as well as the formation of bony spicula and the separation of the periosteum producing what is known as Codman s triangle [26 61 79]

Parosteal and periosteal variants of osteosarcoma have an entirely different clinical course with a higher survival rate [30 36 81 144 145] The histopathological picture in these tumour forms is marked by considerably higher differentiation [144 145] Such tumours as well as extraosseous [107] multiple [2 43] and secondary forms of osteosarcoma such as those resulting from irradiation or Paget s disease are usually excluded from the concept of classical osteosarcoma in the literature [81]

Material

The various investigations comprising the present study were partly based on different clinical series which are presented in Table I The term Contemporary Group indicates that this group of patients is contemporary to the adjuvant therapy initiated in the 1970 s whereas the term Historical Group refers to the group of patients predating the introduction of such treatment

Table I Clinical series reported in Papers I–VI

Paper no	Time period	Geographical area	No of patients	Group	Adjuvant therapy	
I	1938–1959	Karolinska Hospital	105	–	–	
II	1952–1972		35	Historical	–	
	1972–1974	Sweden	44 (23+21)	Contemporary	interferon	(21)
III	1952–1972	Karolinska Hospital	35	Historical	–	
	1972–1974	Sweden (excl Karolinska Hospital)	23	Contemporary	–	
IV	1972–1978	Karolinska Hospital	33	–	interferon	(33)
V	1972–1974	Sweden	44	Contemporary	interferon	(21)
VI	1976–1979	Karolinska Hospital	15	–	interferon	(15)

Patients with classical primary osteosarcoma were included in all series Diagnosis was consistently based on both clinical and radiological findings and on light microscopic examination of tumour specimens In every case included in the series histological examination was carried out by two independent pathologists both thoroughly familiar with tumour diagnostics

No patient included in the series had any signs of metastases at the time of diagnosis The X ray films of the initial lung examination were re-examined in every single case Lung tomography or scanning was not performed in any series to exclude patients who could be expected to have a poorer prognosis

The size of the primary tumour was evaluated in collaboration with a radiologist by measuring the greatest diameter visualized by X ray films in different views Type and duration of symptoms were elicited from the clinical records Blood tests were per formed on admission to hospital before treatment was initiated

Background and aims of the study

For the past several decades the 5 year survival rates for patients with primary osteo sarcoma have ranged between 10 % and 20 %[15 49 81 115] Treatment has for decades consisted in surgery or radiation or a combination of both[49] In the early 1970 s various kinds of adjuvant therapy were introduced in an attempt to improve survival[24 64 128] Initially excellent results were reported for chemotherapy but these were based on very small and often selected series with a short period of observation[42] With increased ob servation periods different centres have reported highly varying effects of this treat ment[15]

Starting in 1972 patients admitted to the Karolinska Hospital without signs of metas tatic spread at the time of diagnosis have been given human leukocyte interferon as adjuvant therapy for a period of 18 months[129] The project was started as a pilot study and the initial results showed a considerably higher survival rate in comparison with a his torical control group[128] The study has since been extended and at present comprises 42 patients

No studies have been published using randomized treatment protocols to compare adjuvant treatment of osteosarcoma (high-dose cytostatics or interferon) with non adjuvant treatment Evaluation of the metastasis free rate and survival has consequently been based on historical control series[15 24 49 56 64 115]

During recent years the validity of such historical control series has been called in question[50 91 112 122 139] One reason is that diagnosis in recent years presumably is made at an earlier stage and that more active treatment has been adopted especially in cases with metastatic spread of the disease Some centres have moreover reported findings suggesting that the natural history of osteosarcoma itself may be changing[8 42 139]

We are consequently faced with considerable difficulties in evaluating the effect of different kinds of adjuvant therapy in osteosarcoma[50 91 122] The present work was initiated in an attempt to test the reliability of historical controls in clinical trials in osteosarcoma and to elucidate the possible influence of a number of different factors on its course

The following factors were studied Biopsy certain prognostic factors (age sex type and duration of symptoms tumour size and site tumour pathology primary tumour treatment treatment delay treatment of metastases) hormonal and metabolic factors (longitudinal growth dental development growth hormone and somatomedin levels glucose tolerance) blood variables (haemoglobin erythrocyte sedimentation rate leuko cyte and thrombocyte count albumin haptoglobin immunoglobulin aspartate amino-transferase alanine aminotransferase and alkaline phosphatase)

The primary aims of the present study were

1 To investigate the risks of open biopsy in the diagnosis of osteosarcoma
2 To study the value and reliability of historical control series by an analysis of factors assumed to affect prognosis
3 To compare a historical and a contemporary group with respect to metastasis free rate and survival in relation to prognostic factors
4 To study the internal and mutual relationship between certain prognostic factors and blood variables
5 To study longitudinal growth and dental development in osteosarcoma patients
6 To study glucose metabolism in osteosarcoma patients by the glucose infusion test and to determine growth hormone and somatomedin levels

The effect of biopsy on survival of patients with osteosarcoma (I)

Between 1938 and 1959 a consecutive series of 105 patients with primary osteosarcoma without evidence of metastatic spread at the time of diagnosis was treated at the Karolinska Hospital The histopathological and radiological findings in this series have been reported in an earlier study [80] The patients selected from this series for the present study were all under 30 years of age and had a tumour located in the metaphyseal region of a long bone which had been removed by radical surgery i e amputation of the limb or disarticulation No patient had received any kind of adjuvant chemotherapy

Fifty seven patients selected by these criteria could be classified as having classical primary osteosarcoma These patients were divided into two groups Group I includes 24 patients who had an amputation without previous biopsy In these cases diagnosis was based only on clinical and radiological findings and subsequently verified by analysis of operation specimens In Group II comprising 33 patients diagnosis was based on analysis of biopsy material In 8 of these cases frozen sections were obtained with or without vascular occlusion by a proximally placed tourniquet immediately prior to amputation In the remaining 25 cases a two stage procedure was adopted with a mode of 4 days between open biopsy and radical surgery

The two main groups were wholly comparable with respect to such factors as age (mean age 16 3 and 15 7 years respectively) and sex (42 % females in both groups) and similar with regard to tumour site and treatment Seven patients in Group I and as many in Group II had received preoperative radiation therapy The radiation dose varied individually and no standard regimen had been followed

All of the patients had been followed up for more than 5 years and there was no difference in the survival rate for the two groups at this time The 5 year survival rate was 21 % in both groups regardless of whether or not biopsy had been done Analysis of the patients who survived for 5 years would seem to indicate radical surgery as a common denominator

Can historical controls be used in current clinical trials in osteosarcoma?

Analysis of prognostic factors (II)

Two groups of patients with osteosarcoma of the long bones without evidence of metastases at the time of diagnosis were analyzed with respect to factors assumed to influence prognosis One was a historical group comprising 35 patients treated at the Karolinska Hospital during the years 1952–1972, the other a contemporary group including all of the 44 patients treated for osteosarcoma in Sweden during the period 1972–1974 This latter group includes 21 patients admitted to the Karolinska Hospital who received adjuvant therapy with human leukocyte interferon

The clinical records tumour slides and X ray films of both primary tumour and lungs were reviewed independently by the pathologists and clinicians included in a National Cancer Institute (NCI) team visiting Sweden in May 1976 A unanimous diagnosis of primary osteosarcoma was reached for the 35 patients subsequently included in the historical group and the 44 patients comprising the contemporary group

An analysis of prognostic factors showed the two series to be comparable in age with

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5. To study longitudinal growth and dental development in osteosarcoma patients
6. To study glucose metabolism in osteosarcoma patients by the glucose infusion test and to determine growth hormone and somatomedin levels

group when the tumour dose exceeded 45 Gy The percentage of patients treated with this dose was twice as high in this group Disarticulation was more often performed in the historical group whereas amputation was more common in the contemporary group

The differences that could be noted between the two groups with respect to prognostic factors corresponded with the observed differences in metastasis-free rate and survival

The results of this study indicate that there may be a risk involved in using historical controls when evaluating the effect of adjuvant therapy in osteosarcoma especially when the series are small and the observation period is short

Correlation between prognostic factors and blood variables (IV)

Prognostic factors and blood chemistry were recorded at the time of diagnosis prior to any treatment in a consecutive series of 33 patients with primary classical osteosarcoma and scheduled for an 18 month course of adjuvant interferon therapy at the Karolinska Hospital All patients with clinical evidence of metastases on admission were excluded from the series

Analysis of certain blood variables such as haemoglobin leukocyte and thrombocyte counts albumin haptoglobin aspartate aminotransferase (Asat) alanine aminotransferase (Alat) and immunoglobulins produced values within the normal range Both the erythrocyte sedimentation rate and the alkaline phosphatase activity were slightly increased but for this latter blood variable it is very difficult to define reliable normal values for growing individuals

Analysis of prognostic factors showed that one third of the patients were female while the average age for the total series was 20 years and the average duration of symptoms 4 months The tumours averaged 10 cm in diameter and in 13 patients were located distally to the knee or elbow The analysis moreover showed a prevalence of osteoblastic high-grade tumours

The recorded prognostic factors were subsequently related to each other and to the analyzed blood variables The results of this study show that female patients had a higher incidence of less malignant more differentiated fibroblastic tumour types ($p < 0\ 05$) which are assumed to have a better prognosis A distal tumour site was more common for smaller tumours and was found to have less influence on the recorded blood variables ($p < 0\ 001$)

Endocrinology

Longitudinal growth and dental development (V)

Between the years 1972–1974 a total of 44 patients (31 males and 13 females) were registered in Sweden under the diagnosis of osteosarcoma without signs of metastatic spread at that time Information on longitudinal growth from birth until the age of diagnosis was obtained from the records of child health centres and school health services where body height is registered at regular intervals These data provided complete growth curves for 19 patients (9 boys and 10 girls)

Analysis of height measurements at 8 0 years when growth is expected to be linear and at the time of diagnosis – which occurred at a mean age of 13 years for both boys and girls in the series – showed entirely normal growth on comparison with growth curves for other Swedish children at those ages [137] At age 8 a mean height of 128 4 cm was noted for male patients as compared to 128 6 cm for their controls The corre

a mean age of 17 years for the historical and 18 years for the contemporary group Female patients were proportionally fewer in the contemporary group (1 2 4 as compared to 1 1 7) but the difference was statistically not significant Pain was the most frequent presenting symptom in both groups noted for all patients in the historical and 86 % of the contemporary group The average duration of symptoms was 3 months in both groups but the incidence of symptoms was significantly higher in the historical group Similarly a significantly larger tumour size (13 cm as compared to 9 cm) was found in the historical group A tumour size of more than 10 cm was found in no less than 64 % of the patients in this group A significantly higher incidence of poorly differentiated tumours was also noted in the historical group, which moreover showed a tendency toward a more proximal location of the tumour

The study consequently disclosed differences between the two groups with respect to factors which might influence the prognosis The incidence of unfavourable prognostic factors was higher in the historical than in the contemporary group

Metastases and survival (III)

The historical and contemporary groups described in the preceding study (II) did not permit a valid comparison of the metastasis free and survival rates since the contemporary group included 21 patients who had received adjuvant interferon therapy Their exclusion left a contemporary group of 23 patients who did not receive any adjuvant therapy for comparison with the 35 patients in the historical group

All patients were followed up for at least 2 5 years at which time the metastasis free rate was assumed to have attained steady state The incidence of patients without metastases in the contemporary group was 31 % at this time as against 14 % in the historical group A similar relationship could be noted with regard to the survival rate which was twice as high for the contemporary group after 2 5 years follow up In addition a delayed plateau phase was noted for the contemporary group producing a displacement of the survival curve as compared to the historical group This can be ascribed to the considerably more active approach adopted in the contemporary group in the treatment of lung metastases with both pulmonary surgery and high dose chemotherapy Half of the patients in this group but none in the historical group had received surgical treatment for such metastases Furthermore 4 patients in the contemporary group had received high dose chemotherapy as compared to none in the historical group Radiation therapy was given to some patients in either group and in this respect the two groups were comparable

Mean survival time from biopsy to death from the tumour was 19 months for the contemporary group and 13 months for the historical group corresponding to the difference observed between the two groups with respect to the metastasis free rate

Analysis of prognostic factors disclosed that the historical group contained larger (13 cm as compared to 6 cm) and more malignant tumours (71 % osteoblastic Grade IV tumours as compared to 48 %) Similarly a proximal tumour site was more common in the historical group even though about 75 % of all tumours in both groups were located in the knee region Both the sex ratio showing about one third of the patients to be female and the age distribution were comparable in the two groups A higher incidence of symptoms was noted for patients in the historical group who also had shorter intervals between lung X ray check ups

Primary treatment of the tumour was largely the same in the two groups with the exception of a higher incidence of pre operative radiation therapy in the contemporary

group when the tumour dose exceeded 45 Gy The percentage of patients treated with this dose was twice as high in this group Disarticulation was more often performed in the historical group whereas amputation was more common in the contemporary group

The differences that could be noted between the two groups with respect to prognostic factors corresponded with the observed differences in metastasis free rate and survival

The results of this study indicate that there may be a risk involved in using historical controls when evaluating the effect of adjuvant therapy in osteosarcoma especially when the series are small and the observation period is short

Correlation between prognostic factors and blood variables (IV)

Prognostic factors and blood chemistry were recorded at the time of diagnosis prior to any treatment in a consecutive series of 33 patients with primary classical osteosarcoma and scheduled for an 18 month course of adjuvant interferon therapy at the Karolinska Hospital All patients with clinical evidence of metastases on admission were excluded from the series

Analysis of certain blood variables such as haemoglobin leukocyte and thrombocyte counts albumin haptoglobin aspartate aminotransferase (Asat) alanine aminotransferase (Alat) and immunoglobulins produced values within the normal range Both the erythrocyte sedimentation rate and the alkaline phosphatase activity were slightly increased but for this latter blood variable it is very difficult to define reliable normal values for growing individuals

Analysis of prognostic factors showed that one third of the patients were female while the average age for the total series was 20 years and the average duration of symptoms 4 months The tumours averaged 10 cm in diameter and in 13 patients were located distally to the knee or elbow The analysis moreover showed a prevalence of osteoblastic high grade tumours

The recorded prognostic factors were subsequently related to each other and to the analyzed blood variables The results of this study show that female patients had a higher incidence of less malignant more differentiated fibroblastic tumour types ($p < 0.05$) which are assumed to have a better prognosis A distal tumour site was more common for smaller tumours and was found to have less influence on the recorded blood variables ($p < 0.001$)

Endocrinology

Longitudinal growth and dental development (V)

Between the years 1972–1974 a total of 44 patients (31 males and 13 females) were registered in Sweden under the diagnosis of osteosarcoma without signs of metastatic spread at that time Information on longitudinal growth from birth until the age of diagnosis was obtained from the records of child health centres and school health services where body height is registered at regular intervals These data provided complete growth curves for 19 patients (9 boys and 10 girls)

Analysis of height measurements at 8 0 years when growth is expected to be linear and at the time of diagnosis – which occurred at a mean age of 13 years for both boys and girls in the series – showed entirely normal growth on comparison with growth curves for other Swedish children at those ages [137] At age 8 a mean height of 128 4 cm was noted for male patients as compared to 128 6 cm for their controls The corre

sponding figures for girls were 129 1 cm and 127 4 cm, respectively A significant correla tion was noted between the standardized height at 8 0 years and the standardized height at the age of diagnosis ($r = 0\ 88$ $p < 0\ 001$)

A relationship exists between longitudinal growth and tooth eruption [41] Dental maturity was analyzed by a method reported by Filipsson [40] Sufficient data on tooth eruption to permit analysis could be obtained from national and school dental services for 24 patients (16 males and 8 females) Dental development was entirely normal in these osteosarcoma patients as evidenced by the fact that the mean age noted at the reference point on the tooth eruption curve was 8 67 years for male patients as compared to an age of 8 75 years calculated for controls [40] Mean age for female patients and their normal controls[40] was 8 36 and 8 44 years respectively

Both longitudinal growth and dental maturity were consequently found to be normal in this analysis of osteosarcoma patients

Glucose tolerance, growth hormone and somatomedin (VI)

A study of glucose tolerance serum levels of growth hormone and somatomedin and glucose induced insulin secretion was undertaken in a consecutive series of 15 patients with classical osteosarcoma admitted to the Karolinska Hospital All tests were carried out before any treatment was initiated All patients were in good general condition at the time Both the mean duration of symptoms (3 months) and the age and sex distribution were typical for classical primary osteosarcoma High grade osteoblastic tumours predominated in the series

Analysis of blood samples showed that somatomedin A and growth hormone levels were entirely within the normal range for age[17 54 55] in all patients at the time of diagnosis This finding is consistent with the normal growth rate observed for osteosarcoma patients in the preceding study (V)

Glucose intolerance has been reported for osteosarcoma patients [53] Glucose infusion tests (GIT)[18] were performed in all 15 patients to study the mechanism underlying the reported glucose intolerance in osteosarcoma No difference in basal glucose and insulin levels was noted between the osteosarcoma patients and healthy controls[32] matched by weight height and age However the disappearance rate of glucose[60] (K value) after glucose infusion was significantly decreased in the patient group This difference was not related to age or sex

A typical biphasic insulin response to the GIT was noted both in the osteosarcoma patients and in the control group There was no difference in initial insulin response between the two groups but during the latter part of the test significantly higher insulin levels were noted for the osteosarcoma patients Decreased glucose tolerance might be explained by reduced insulin sensitivity and analysis of glucose and insulin response to the GIT by means of a mathematical model[19] did in fact demonstrate reduced insulin sensitivity in the osteosarcoma patients

The results of this study showed that somatomedin A and growth hormone levels were within the normal range for age in the osteosarcoma patients The decreased glucose tolerance noted in these patients may be explained by reduced insulin sensitivity

CHAPTER III – GENERAL DISCUSSION

Biopsy and diagnosis

The diagnosis of osteosarcoma may present considerable difficulties even when aided by histologic examination of tumour tissue [28] As a rule a diagnosis of primary classical osteosarcoma will have to be based on the combined evidence provided by the patient s history the X rays of both primary tumour and lungs and histologic analysis of a representative specimen of tumour tissue [14 77 136] The often polymorphous character of the tumour[36 79] urges the need of obtaining specimens from different parts of the neoplastic growth at the time of biopsy [14] For this reason open biopsy is to be preferred since aspiration or drilling[78 96 135 136] usually fails to provide sufficient material for analysis from different parts of the bone tumour such as the periosteum cortex or marrow and when indicated extra-osseous soft tissue elements

The advisability of obtaining specimens from several portions of the tumour by surgical biopsy prior to definitive surgery has been questioned on the suspicion that manipulation of the tumour might entail a risk of tumour cell embolisation [34 44 45 95 109 142] which in its turn is suspected to increase the risk of metastasis This theory is supported by animal studies [71 89 143] Although no evidence has been reported of increased metastasis in man [136] tumour cells have been demonstrated in the blood of patients with malignant tumours subjected to surgery [44 96 134 141]

In our first study (I) we investigated whether open biopsy and a delay between biopsy and definitive surgery had any effect on the long term prognosis Although small the series included in this study are comparable to the clinical series reported in connection with studies concerning adjuvant therapy in osteosarcoma in recent years [15] No patient had any signs of metastases at the time of diagnosis and in all cases the tumour was removed by radical surgery i e amputation or disarticulation of the affected limb

Our study demonstrated no difference in the 5 year survival rate between patients who had an amputation without prior biopsy and those who had a biopsy The survival rate of 21 % noted for both groups is consistent with the 5 year figures reported for large series [27 49 56 76 81 83 86 101 136] Moreover we found no survivors among patients whose definitive surgery was delayed for more than 30 days after biopsy

The radiological and clinical features of benign conditions like osteomyelitis may simulate osteosarcoma and the necessity of confirming the diagnos s by open biopsy has in recent years been strongly emphasized [15] Considering the important diagnostic benefits to be gain d from open biopsy and the fact that our study failed to demonstrate any negative effect on the long term prognosis it would seem that this procedure is to be recommended However the series will have to be enlarged to permit more reliable conclusions Although the observed difference between the two groups is 0 % a confidence interval (95 %) of 0 – 21 % can be calculated

An alternative biopsy procedure involving proximal vascular occlusion by one or two tourniquets and analysis of frozen sections of tumour tissue during operation has been discussed by some authors [27 36 72 80 135 138] However many pathologists feel that frozen sections are unsatisfactory for a reliable diagnosis of osteosarcoma since analysis of bone tissue often requires special methods of preparation It has moreover been demonstrated that a proximally applied tourniquet primarily serves to occlude the venous flow but does not prevent intra-osseous circulation and consequently cannot be claimed to provide a wholly reliable safeguard against tumour cell embolisation [77]

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for patients treated only by conventional methods like surgery and irradiation in comparison with earlier series of similarly treated patients [8, 138] In this context the selection of patients was discussed since patients with a presumably better prognosis might be more liable to be admitted to one centre than to another [8, 42, 81] Another question raised was whether refined radiological diagnostic techniques including lung tomography and scintigraphy might contribute to the exclusion of patients with metastatic spread at the time of diagnosis implying a poorer prognosis [138] The higher survival rate in patients with lung metastases could to some extent be explained by the more active approach adopted in the treatment of such metastases All this has cast doubt on the reliability of historical controls

In the study undertaken at the Karolinska Hospital of adjuvant interferon treatment in patients with classical osteosarcoma without evidence of metastatic spread we used a historical control group of 35 patients treated at this hospital between 1952 and 1972 To make evaluation of the effect of interferon treatment more reliable and to reduce the risk of selecting patients characterized by factors tending to influence prognosis in a positive or negative way we collected all patients in Sweden who during the years 1972–1974 received a diagnosis of classical primary osteosarcoma without evidence of metastatic spread at that time and who did not receive adjuvant therapy Together with the patients treated with interferon during the same period this produced a contemporary group of 44 patients A comparative analysis of a number of prognostic factors disclosed appreciable differences between the historical and the contemporary group

Sex

It has earlier been suggested that female osteosarcoma patients have a better prognosis [45, 80, 102, 106, 119, 138] and the question has been raised whether this might be related to the female sex hormone estrogen [84, 120] In large series of primary osteosarcoma the proportion of females is usually reported as one third [26] In our study of prognostic factors (II) the historical group included slightly more female patients than expected while the ratio between females and males in our study on metastases and survival (III) was 1 2 In our analysis of prognostic factors and blood variables (IV) we found a longer duration of symptoms for female patients and a higher incidence of less malignant i e low-grade fibroblastic tumours than among the males Moreover it may be noted that two thirds of the 12 patients surviving without tumour recurrence at the 5 year follow up in our study on biopsy and survival (I) were female whereas the sex distribution was reversed in the original series of 57 patients

Age

One of the criteria commonly used to define the concept of classical primary osteosarcoma is that it affects patients under 30 years of age [139] The Karolinska Hospital material includes 3 patients in the historical group and 4 in the contemporary group who were over 30 but otherwise manifested a clinical picture wholly typical of primary osteosarcoma In some earlier studies a more favourable prognosis for older patients has been discussed [27, 80, 83, 101] In our study correlating prognostic factors and blood variables (IV) we noted that the duration of symptoms increased with age which might be ascribed to slower tumour growth in older patients No correlation was found between age and tumour pathology size or location

Surgery

Authors discussing the level of amputation seem to be agreed that tumours located distally to the elbow or knee should be removed by transmedullary amputation of the proximal part of the limb i e the thigh or upper arm [36 135] Concerning the most common tumour site the distal femur opinions are more divided Some authors feel that this tumour site demands disarticulation at the hip joint whereas others recommend proximal femoral amputation [14 27 36 63 76 86 134] Underlying the demand for extreme radicality are some reports demonstrating the occurrence of so called skip lesions that is neoplastic foci at a different site from the primary tumour but within the same limb usually in the same long bone but occasionally with a transarticular location [14 35 37] Although these findings have been called in question,[29 66 78] the intramedullary encroachment observed in amputation specimens in some cases suggests that this may be more extensive than can be visualized by the preoperative X rays [134 146] Bone scans and tomography have regrettably proved to be of limited value as an additional aid in the preoperative assessment of tumour growth [36 52 134] Angiography is primarily useful in demonstrating extraosseous tumor growth [36 73 134 150]

The introduction in recent years of adjuvant therapy which is believed to have an effect on micrometastasis has led many surgeons to revise their views on amputation surgery and en bloc resection of the tumour has been frequently adopted instead [1 65 85 93,110] This implies removal of the tumour with a smaller safe margin often allowing preservation of an adequately functioning limb The defect left by the tumour is replaced either by foreign implants such as plastic or metal prostheses or by autologous tissue such as bone grafts [93]

If local resection is to satisfy the demand for complete radicality it will be necessary to extirpate the site of any previous biopsy incision in one single piece with the rest of the tumour This places additional demands on an adequate biopsy technique including selection of the right site for incision and caution in manipulating tumour tissue [80 93 135] The same surgeon will often be required to perform both biopsy and definitive surgery

At the Karolinska Hospital adjuvant therapy with human leukocyte interferon was introduced in 1971 and so far a consecutive series of 42 osteosarcoma patients without radiological evidence of metastases has been treated Fifteen of these 42 patients were operated upon with local resection of the tumour following open biopsy [93] Six of these patients have so far been followed up for at least five years and four are alive without evidence of tumour recurrence while two have died from other causes

Prognostic factors

Prior to the 1970 s the survival rate for osteosarcoma patients was low often less than 20 % after a 5 year follow up [27 49 56 77 80 81 83 86 97 135] In 1972 the first report on the positive results of chemotherapy (methotrexate adriamycin) in metastatic osteosarcoma were published [23 62] followed by the introduction of systematic treatment by various cytostatics as adjuvant therapy in patients with osteosarcoma without evidence of metastatic spread at the time of diagnosis Early reports showed promising results but were based on small series and short observation periods [24 64 128] With longer observation periods the results were somewhat less favourable and today combined treatment with different drugs often administered in maximum doses yields a 5 year survival rate of 40–50 % [25 38 48 57 66 69 99 112 133]

Around 1976 the question was raised whether the natural history of osteosarcoma might be changing since some centres in recent years had noted higher survival rates

for patients treated only by conventional methods like surgery and irradiation in comparison with earlier series of similarly treated patients[8, 138] In this context the selection of patients was discussed since patients with a presumably better prognosis might be more liable to be admitted to one centre than to another[8, 42, 81] Another question raised was whether refined radiological diagnostic techniques including lung tomography and scintigraphy might contribute to the exclusion of patients with metastatic spread at the time of diagnosis implying a poorer prognosis[138] The higher survival rate in patients with lung metastases could to some extent be explained by the more active approach adopted in the treatment of such metastases All this has cast doubt on the reliability of historical controls

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Type and duration of symptoms

Pain is the most common symptom followed by swelling[26 81,83 136] Pathological frac ture of the involved bone was noted in a few cases, but generally no prognostic impor tance has been attached to this in the literature[81] The incidence of symptoms was higher in the historical than in the contemporary group but their duration which is reported to be correlated to prognosis[28 81,83 118] was the same in both groups The more favour able prognosis associated with a longer duration of symptoms may be ascribed to a better individual reaction to the tumour resulting in slower tumour growth[81 125] This assump tion would also seem to be consistent with the positive correlation observed in our study on prognostic factors and blood variables (IV) between duration of symptoms and low grade tumours as well as higher serum levels of immunoglobulin G

Size and location of tumour

In our study on prognostic factors and survival (III) we found that tumour size as meas ured by the greatest diameter on the X-rays on the average was twice as large in the historical group as in the contemporary group A significant difference in tumour size between these two groups was also observed in our analysis of prognostic factors (II) which yielded a tumour size exceeding 10 cm in 64 % of the patients in the historical group A considerably poorer prognosis has been reported for tumours exceeding 10 cm in diameter[81 83 118 136] In addition our study on prognostic factors and blood variables (IV) disclosed a correlation between tumour size and its location since we found distal tumours to be smaller They were also associated with higher levels of haemoglobin and albumin a lower erythrocyte sedimentation rate and a lower haptoglobin serum level Although it should also be easier to recognize distally located tumours at an earlier stage this study (IV) failed to demonstrate a positive correlation between tumour size and dura tion of symptoms Similarly there was no correlation between tumour size and tumour pathology

The prognostic significance of tumour location has been a subject of discussion in the literature Some authors consider distal location a favourable sign[27 29 49 75 81 147 148] whereas others fail to establish such a relationship[80 83 102 118 119 136] Although the difference was statistically not significant the historical group contained a greater num ber of proximally located tumours

Tumour pathology

Several authors classify osteosarcoma according to the dominant cell type in an osteo blastic chondroblastic and fibroblastic variety[28 36 102] The value of this classification however has been called in question[80 81 101 136] We have mentioned earlier that it is important to base histological examination on serial sections since different parts of the tumour may present varying features[26 36] Some authors feel that the chondroblastic type is associated with the poorest prognosis[101 119] whereas Dahlin s studies identify the osteoblastic type as the most malignant form of osteosarcoma[27 28]

A predominance of osteoblastic Grade IV tumours was found in the historical group and this group totally included significantly more Grade IV tumours Earlier reports have questioned the value of malignancy grading on the basis of tumour cell differentiation[27 81 83 101 136 141 148] The literature provides no information to suggest a better prog nosis for fibroblastic tumours but our correlation study (IV) demonstrated that this type was more common in low grade tumours and had a higher incidence among female

patients Ten of the 33 patients included in this study were followed up for 5 years and 5 of them survived without signs of tumour recurrence Four of these 5 patients (80 %) had a fibroblastic tumour as compared to 8 of the 33 patients (24 %) in the original series All 33 patients received adjuvant interferon therapy for an equally long period The presence of osteoid in the tumour tissue could be clearly demonstrated and histo logically the tumours could be clearly differentiated from fibrosarcoma

The historical group consequently showed a higher incidence of large sized proximally located and high-grade osteoblastic tumours than the contemporary group Such factors are assumed to be indicative of a poorer prognosis This was investigated in our study on metastases and survival (III) in which patients who had received adjuvant interferon therapy were excluded from the contemporary group A comparison between the two new groups showed that the differences with respect to prognostic factors persisted

A clear difference could be noted both in the incidence of metastases and in the sur vival rate after 2 5 years follow up At this point of time the incidence of patients with out metastases was twice as high in the contemporary group and the same relation was observed with respect to the number of survivors In an attempt to explain these dif ferences we also studied the methods of treatment adopted in the two groups

Treatment

Radiation therapy For decades the treatment of primary osteosarcoma has consisted in surgery or irradiation or a combination of both[49] The extremely low 5 year survival rate observed in patients treated only by surgery led Cade[13 14] to introduce treatment of primary tumours with preoperative irradiation in high doses of 60–90 Gy followed by a 6 month period of observation prior to definitive surgery This was intended to avoid surgery for those patients who developed metastases during the 6 month interval Micro metastases are assumed to be present in a majority of patients – according to some authors up to 80 [7] – at the time of diagnosis Studies of large seri s have shown that lung metastases can be radiologically verified in more than half of the patients within 6 months of diagnosis[15 36 86 115 136]

Osteosarcoma is not consider d to be particularly sensitive to radiation[63] and treat ment of the primary tumour by irradiation only especially with suboptimal doses often leaves a viable tumour which in due time produces pain pathological fractures and an impaired general condition[36 68 76 82 132] The 5 year survival rate for patients treated by irradiation only is in many studies reported as lower than that resulting from surgical treatment only Some studies report no better results from a combination of surgery and irradiation[21 36 49 80 83 118 136] but it may be suspected that these findings are biased by the selection of patients not suited for surgical treatment

With the introduction of adjuvant therapy which is most effective when there is limited tumour involvement and the primary tumour is removed at an early stage pre operative radiation th rapy has been virtually discarded and the treatment is today pri marily used as a palliative procedure for inoperable tumours[21] Cade claimed that high radiation doses were required to achieve antitumoral effects[14] In the contemporary control group radiation therapy with doses exceeding 45 Gy was given to twice as many patients as in the historical group A comparable number of patients in either group was scheduled for a 6-month observation period on conclusion of irradiation before surgical treatment was to be initiated These patients are included in the study Two patients in the contemporary group and 5 in the historical group developed metastases during this 6 month interval and had no surgery This should not influence a prognostic comparison

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A predominance of osteoblastic Grade IV tumours was found in the historical group and this group totally included significantly more Grade IV tumours Earlier reports have questioned the value of malignancy grading on the basis of tumour cell differentiation [27 81 83 101 136 141 148] The literature provides no information to suggest a better prog nosis for fibroblastic tumours but our correlation study (IV) demonstrated that this type was more common in low grade tumours and had a higher incidence among female

counteract this microscopic tumour spread have been suggested [5,48] During the 1970 s various cytostatics have been introduced as adjuvant therapy [15] Following initial reports of highly successful results various centres throughout the world have subsequently reported results based on larger series and longer follow up periods providing an average survival rate of about 50 % but the results of different centres vary wid ly [15] Treatment with a combination of different cytostatics – primarily adriamycin and methotrexate – in doses frequently approaching the maximum dose has been associated with severe side effects Even lethal effects have been reported [88]

Attempts have also been made to treat osteosarcoma patients with anticoagulants transfer factor and various other regimens of immunological therapy [11 22 33 51 58 112 114] As a rule su h treatment is recommended only as a supplement to radical surgery and adjuvant chemotherapy In many cases adjuvant therapy of different kinds is founded on in vitro and animal experiments [16 47 48 126 127] and some authors have succinctly described the state of adjuvant therapy in osteosarcoma today as presenting more ques tions than answers [90]

To summarize our comparison of prognostic factors in a historical and a contemporary group in several studies (II–IV) has demonstrated a number of differences between the two groups (Table II)

Table II Difference in prognostic factors between the historical and the contemporary group

Prognostic factors	Historical versus contemporary group
Symptoms	Higher incidence
Tumour size	Larger
Tumour pathology	Higher incidence of osteoblastic and Grade IV tumours
Radiation therapy	Lower incidence
Surgery	Higher incidence of disarticulation
Treatment of pulmonary metastases	Less active (no surgery or high-dose chemo therapy)

The historical group features a higher incidence of unfavourable prognostic factors such as a proximal tumour location larger and more malignant tumours In addition a more aggressive approach to the treatment of metastases presumably resulting in increased sur vival was noted in the contemporary group Up to-date curves for the two groups studied in our analysis of metastases and survival (III) ar presented in Fig 1 and 2 which also show the results for the 42 interferon patients to date It remains to be seen whether the observed differences between the two groups with respect to prognostic factors persist when the series are enlarged There is an obvious risk however in evaluating the effect of adjuvant therapy by comparison of small clinical series with a short follow up An analysis of prognostic factors in the series to be compared is imperative especially in non randomized studies

since both groups originally included an equal number of patients scheduled for this form of treatment

Prophylactic irradiation of the lungs to destroy micrometastases has been tested in prospective randomized studies without providing a conclusive answer [7,12,105] No patient in any of the groups included in the present study has received such adjuvant treatment

Surgery Disarticulation was considerably more common among patients in the historical than in the contemporary group This operation was performed in almost half of the patients in the historical group partly because of a higher incidence of proximally located tumours and probably partly owing to the prevailing opinion of the day that disarticulation was necessary to ensure radicality This will scarcely influence a prognostic analysis however since macroscopically radical removal of the tumour was carried out in all patients subjected to surgery

Treatment of lung metastases Metastasis of osteosarcoma is hematogenous and predominantly involves the lungs [14,26,61,67,79] In spite of the fact that the average duration of symptoms is less than 6 months it is assumed that the majority of patients[14] – probably up to 80 % – have lung metastases at the time of diagnosis [8,27,56,64,77] Prior to the 1970 s the approach towards treatment of lung metastases was highly conservative and as a rule any treatment given was purely palliative

The reports claiming successful results with methotrexate or adriamycin therapy for macroscopic metastases in osteosarcoma marked the beginning of a more aggressive approach to the treatment of such metastases Optimal antitumoral effect was observed when there was limited tumour involvement [36,48,56,110] Adjuvant therapy has also produced a somewhat changed course of the disease in that fewer and often solitary metastases have been noted to occur and sometimes at a later stage [4,10,63,98,99,130] As a consequence surgical removal of lung metastases by lobe resection lobectomy and sometimes total pulmectory seemed more justified and in recent years promising results have been reported of such surgery [3,12,59,87,111,113,121,124,140]

That a similar change in attitude with respect to the treatment of lung metastases had taken place in Sweden was evident from our study comparing the historical and contemporary groups in this respect (III) In almost half of the patients in the contemporary group who developed lung metastases these were removed by surgery while 25 % of these patients received high dose chemotherapy No patient in the historical group had pulmonary surgery while high dose chemotherapy was not available at the time The difference in the two groups with respect to the treatment of lung metastases to some extent serves to explain the difference in the survival rates noted at the 2 5 year follow up Whether active treatment of lung metastases delays the plateau phase in the survival curve cannot be definitely concluded from our study after 2 5 years follow up According to earlier studies lung metastases were noted in 80 % of the patients within one year and since all patients in our study had been followed up for at least 2 5 years this was the time selected for comparison of the two groups A combination of adjuvant therapy and active treatment of lung metastases might be expected to produce a further delay of the plateau phase in the curves expressing metastasis free and survival rates and thus urge the need for an increased follow up period

Adjuvant therapy Dissemination of the tumour prior to diagnosis and initial treatment is considered of crucial importance for prognosis and various forms of treatment to

counteract this microscopic tumour spread have been suggested [5, 48] During the 1970 s various cytostatics have been introduced as adjuvant therapy [15] Following initial reports of highly successful results various centres throughout the world have subsequently reported results based on larger series and longer follow up periods providing an average survival rate of about 50 % but the results of different centres vary widely [15] Treatment with a combination of different cytostatics – primarily adriamycin and methotrexate – in doses frequently approaching the maximum dose has been associated with severe side effects *Even lethal effects have been reported* [88]

Attempts have also been made to treat osteosarcoma patients with anticoagulants transfer factor and various other regimens of immunological therapy [11, 22, 33, 51, 58, 112, 114] As a rule such treatment is recommended only as a supplement to radical surgery and adjuvant chemotherapy In many cases adjuvant therapy of different kinds is founded on in vitro and animal experiments [16, 47, 48, 126, 127] and some authors have succinctly described the state of adjuvant therapy in osteosarcoma today as presenting more questions than answers [90]

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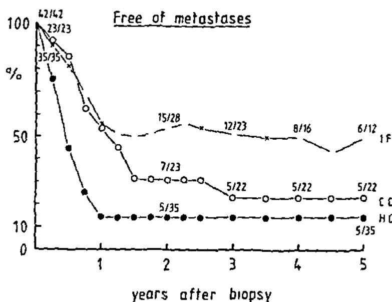


Fig 1 Up to date metastasis-free rate in interferon treated patients (x—x N=42), contemporary control group (o—o N=23) and historical control group (•—• N=35)

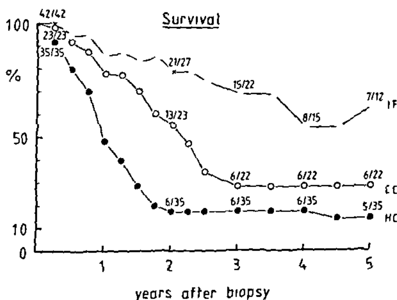


Fig 2 Up to date survival rate in interferon treated patients (x—x N=42) contemporary control group (o—o N=23) and historical control group (•—•) N=35)

Endocrinology

Growth

Osteosarcoma is most common in young individuals and its incidence is almost twice as high among males with a peak usually coinciding with the pubertal growth spurt [27,74,81,100,119,147]. It has been suggested that both pathogenesis and prognosis are influenced by hormonal factors [53]. Female patients are claimed to have a better prognosis [45,80,102,106,138] and in vitro studies have demonstrated estrogen to have a positive antitumoral effect [120]. The predominant site of the tumour is the metaphyseal region of the long bones and in the majority of patients the tumour is located in the region of the knee [27,36].

Earlier studies have reported a predominance of tall individuals [21,46,74,100,120] but no analysis has been performed to determine whether osteosarcoma is associated with an abnormal rate of growth. Such an analysis has been attempted in our study of individual growth curves of osteosarcoma patients (V). In contrast to the earlier studies which were based on cross sectional growth data instead of individual growth curves, our analysis failed to demonstrate any deviations in longitudinal growth. A relationship exists between longitudinal growth and tooth eruption [41]. In our analysis dental maturity was found to be normal and consequently supported our findings regarding normal growth in osteosarcoma patients. The average duration of symptoms, reported as 3–10 months in earlier studies [49,81,136], was 3 months for the patients in this study. The possibility of the tumour itself stimulating growth could therefore not be excluded, since the period from the presumed onset of the disease until diagnosis was too short to allow detection of growth rate increment. The sex distribution in this study was not wholly typical for osteosarcoma patients. The proportion of female patients was larger than might be expected, but since comparisons were made within each sex this could not influence the results.

Additional evidence to support our finding of normal growth in osteosarcoma patients was provided by a subsequent study (VI), which showed serum levels of somatomedin A and growth hormone to be within the normal range for age for these patients. Earlier studies reporting increased levels of these hormones may have failed to take sufficient account of variations in age, especially with respect to somatomedin levels.

Glucose tolerance

A high incidence of diabetes mellitus has been reported for tumour patients [70]. Glucose intolerance may be ascribed to stress and malnutrition factors in cancer patients in poor general condition [31,149]. Glucose homeostasis may also be influenced by polypeptide hormone secretion by the tumour tissue [108]. Earlier studies have reported glucose intolerance in osteosarcoma patients in combination with hyperinsulemia [53]. In our study (VI) glucose tolerance was analyzed in 15 osteosarcoma patients. This study provided evidence of glucose intolerance, consistent with earlier reports, and showed that this could most likely be ascribed to decreased peripheral insulin sensitivity. At present we can only speculate whether this decreased sensitivity should be attributed to hormones or hormone homologues secreted by the tumour tissue. In order to analyze this, glucose infusion tests were performed in several patients after removal of the tumour and no change in glucose tolerance or insulin sensitivity was noted in these cases (Unpublished observations).

There was considerable individual variation in insulin sensitivity, but all patients manifesting extremely low insulin sensitivity developed metastases. The follow up period

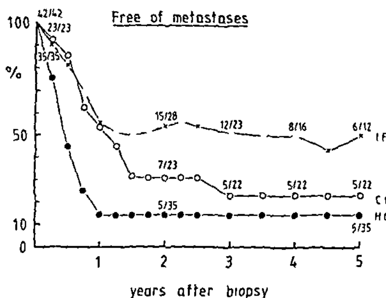


Fig 1 Up to date metastasis free rate in interferon treated patients (x — x N=42) contemporary control group (○ — ○ N=23) and historical control group (● — ● N=35)

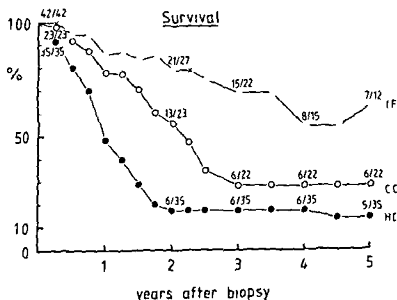


Fig 2 Up to date survival rate in interferon treated patients (x — x N=42) contemporary control group (○ — ○ N=23) and historical control group (● — ●) N=35)

CHAPTER 4 – GENERAL SUMMARY AND CONCLUSIONS

The present study permits the following observations and conclusions

1 Open biopsy is advisable in the diagnosis of osteosarcoma in view of the many advantages offered by this procedure and the fact that no negative effect on long term survival was demonstrated On the other hand too long a delay between biopsy and definitive surgery would not seem to be advisable

2 Comparison between a historical and a contemporary group demonstrated a pre dominance of unfavourable prognostic factors in the historical group This group was characterized by a higher incidence of symptoms larger and histologically more malignant tumours and a higher incidence of proximally located tumours

3 A contemporary and a historical group without adjuvant tumour treatment mani fested clear differences with respect to the incidence of metastases and the sur vival rate after 2 5 years follow up The percentage of survivors and patients with out metastases was twice as high in the contemporary group at this time The in creased survival rate for patients with lung metastases in the contemporary group could partly be ascribed to the more aggressive approach adopted in the treatment of such metastases

4 Evaluation of the effect of any therapy in non randomized studies requires an analysis of prognostic factors to disclose possible differences between the clinical series There would seem to be a definite risk in using historical controls in such studies based on small series with a short period of observation

5 The blood variables studied in osteosarcoma patients provided values within the normal range with the exception of the erythrocyte sedimentation rate

6 Correlation analysis disclosed that female patients had a higher incidence of low grade tumours and that a distal tumour site was more common in tumours of smaller size

7 Normal longitudinal growth and normal dental development were found in osteo sarcoma patients This finding is supported by the results of our study demon strating normal serum levels of somatomedin A and growth hormone

8 Decreased glucose tolerance was demonstrated in our osteosarcoma patients and could most likely be attributed to decreased insulin sensitivity

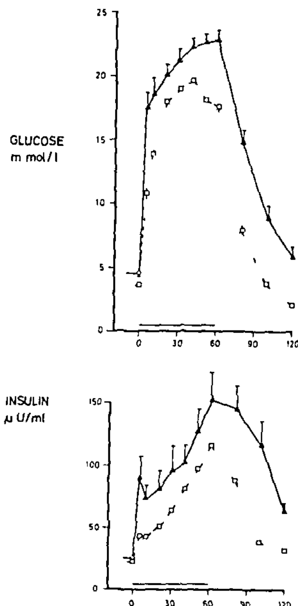


Fig 3 Glucose and insulin levels during GIT in single patient free of metastases after 3 5 years (□—□) and 8 patients with metastases within one year (▲—▲ vertical bars indicate SEM)

varies for the patients included in this consecutive series but the patient without metastases after the longest follow up (3 5 years) belonged to the group manifesting normal insulin sensitivity Insulin and glucose response to the glucose infusion test for this patient as compared to the 8 patients who developed metastases within one year (Fig 3) showed a tendency to lower serum glucose levels during the test and a more rapid decline of the serum glucose level on conclusion of the test Both the insulin level and the calculated K value were within the normal range for this patient whereas K values were significantly decreased for the patient group as a whole

Whether insulin sensitivity may be useful as a prognostic factor in osteosarcoma will be investigated in further studies based on a larger number of patients with a sufficiently long follow up to permit more reliable prediction of the long term outcome

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The people who have assisted me directly or indirectly in the preparation of this book are too numerous to thank them all individually To some of them however I owe a special debt of gratitude which I wish to acknowledge here

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REFERENCES

1 Adamson U Aparisi T Brostrom L A Cantell K Einhorn S Hall K Ingimarsson S Nilsonne U Strander H & Soderberg G (1977) Interferon treatment of human osteosarcoma Study week of the Pontifical Academy of Sciences Vatican City Oct 17–21 In press

2 Amstutz H (1969) Multiple osteogenic sarcomata – metastatic or multicentric Cancer *24* 923–931

3 Beattie E Martini N & Rosen G (1975) The management of pulmonary metastases in children with osteogenic sarcoma with surgical resection combined with chemotherapy Cancer *35* 618–621

4 Benjamin R Baker L O Bryan R Moon T & Gottlieb J (1978) Chemotherapy for metastatic osteosarcoma studies by the MD Anderson Hospital and the SW Oncology Group Cancer Treat Rep *62* 237–238

5 Bennett J (1977) Adjuvant oncotherapy The treatment of systemic micrometastases Adv Surgery *11* 375–384

6 Boyer L (1807) The lectures of Boyer upon diseases of the bone arranged by A Richerand John Callow London

7 Breuer K Cohen P Schweisguth O & Hart A (1978) Irradiation of the lungs as an adjuvant therapy in the treatment of osteosarcoma of the limbs Results of a controlled clinical trial by the Clinical Cooperative Group on Radiotherapy of the EORTC Eur J Cancer *14* 461–471

8 Breuer K & van der Schueren E (1979) Adjuvant therapy in the management of osteosarcoma Need for critical reassessment In Recent Results in Cancer Research Eds Mathe Salmon & Bonadonna Springer Verlag 5–16

9 Broders A C Hargrave R & Meyerding H W (1939) Pathological features of soft tissue fibrosarcoma Surg Gyn Obst *69* 267–280

10 Brostrom L A Ingimarsson S Strander H & Soderberg G (1979) Adjuvant interferon treatment and the late development of cerebral metastases in a patient with osteosarcoma Acta Orthop Scand In press

11 Byers V Le Cam L Levin A Johnston J & Hackett A (1979) Immunotherapy of osteogenic sarcoma with transfer factor Cancer Immunol Immunother *6* 243–253

12 Caceres E Zaharia M Moran M & Tejada F (1978) Adjuvant whole lung radiation with or without adriamycin treatment in osteogenic sarcoma Cancer Treat Rep *62* 297–299

13 Cade S (1947) Primary malignant tumours of bone Br J Radiol N S XX *229* 10 18

14 Cade S (1955) Osteogenic sarcoma – a study based on 133 patients J Roy Coll Surg Edinburgh *1* 79 111

15 Cancer Treatment Reports (1978) Proceedings of the Osteosarcoma Study Group Meeting Febr 1978 National Cancer Institute NIH USA Cancer Treat Rep *62* 187–313

16 Cantell K Pyhala L & Strander H (1974) Circulating human interferon after intramuscular injection into animals and man J Gen Virol *2* 453–455

17 Cerasi E Della Casa L Luft R & Roovete A (1966) Determination of human growth hormone (HGH) in plasma by a double antibody radioimmunoassay Acta Endocr (Kbh) *53* 101–120

42 Fisher D (1978) Osteosarcoma Advances in treatment or changing natural his tory Lancet 8 82–82

43 Fitzgerald R Dahlin D & Sim F (1973) Multiple metachronous osteogenic sar coma J Bone Jt Surg *55–A* 595–605

44 Foss O Brennhovd I Messelt O Efskin J & Liverud K (1966) Invasion of tumour cells into the bloodstream caused by palpation or biopsy of the tumour Surgery *59* 691–695

45 Foster E & Shambaugh E (1964) Survival experience of patients with cancer of bone 1945–1959 Proc V Natl Cancer Conf J B Lippincott Co Philadelphia 385–396

46 Fraumeni J (1967) Stature and malignant tumors of bone in childhood and adolescence Cancer *20* 967–973

47 Frei E (1976) Methotrexate revisited Med Ped Oncol *2* 227–241

48 Frei E Jaffe N Skipper H & Gero M (1977) Adjuvant chemotherapy of osteogenic sarcoma – Progress and Perspectives In Adjuvant Therapy of Cancer Eds Salmon and Jones Elsevier N Holland Biomed Press Amsterdam 49–64

49 Friedman M & Carter S (1972) The therapy of osteogenic sarcoma Current status and thoughts for the future J Surg Oncol *4* 482–509

50 Gehan E (1978) Comparative clinical trials with historical controls a statistician s view Biomed Spec Issue *28* 13–19

51 Gilchrist G Ivins J Ritts R Pritchard D Taylor W & Edmonson J (1978) Adjuvant therapy for nonmetastatic osteogenic coma An evaluation of transfer factor versus combination chemotherapy Cancer Treat Rep *62* 289–294

52 Goldman A Becker M Braunstein P Francis K Genieser N & Firooznia H (1975) Bone scanning-osteogenic sarcoma Correlation with surgical pathology Am J Roentgenol Rad Ther Nucl Med *124* 83–90

53 Goodman M McMaster J Drash A Diamond P Kappakas G & Scranton P (1978) Metabolic and endocrine alterations in osteosarcoma patients Cancer *42* 603–610

54 Hall K Takano K & Fryklund L (1974) Radioreceptor assay for somatomedin A J Clin Endocr *39* 973–976

55 Hall K Brandt J Enberg G & Fryklund L (1979) Immunoreactive somato medin A i human serum J Clin Endocr *48* 271–278

56 Handelsman H & Carter S (1975) Current therapies in osteosarcoma Cancer Treatm Rev *2* 77–83

57 Holland J & Cortes E (1978) Surgical adjuvant chemotherapy in sarcomas Anti biot Ch mother *24* 95–99

58 Hoover H Ketcham A Millar R & Gralnick H (1978) Osteosarcoma – Im proved survival with anticoagulation and amputation Cancer *41* 2475–2480

59 Huang M Takita H & Douglass H (1978) Lung resection for metastatic osteo genic sarcoma J Surg Oncol *10* 179–182

60 Ikkos D & Luft R (1957) On the intravenous glucose tolerance test Acta Endocr (Kbh) *25* 312–334

61 Jaffe H (1958) Tumours and tumorous conditions of the bones and joints Lea & Febiger Philadelphia

62 Jaffe N (1972) Recent advances in the chemotherapy of metastatic osteogenic sarcoma Cancer *30* 1627–1631

63 Jaffe N (1976) Osteogenic sarcoma – State of the art with high-dose metho trexate treatment Clin Orthop *120* 95–102

18 Cerasi E & Luft R (1967) The plasma insulin response to glucose infusion in healthy subjects and in diabetes mellitus Acta Endocr (Kbh) *55* 278–304

19 *Cerasi E Fick G & Rudemo M (1974)* A mathematical model for the glucose induced insulin release in man Eur J Clin Invest *4* 267–278

20 Codman E (1925) Bone Sarcoma An interpretation of the nomenclature used by *the Committee* on the Registry of Bone Sarcoma of the American College of Surgeons P B Hoeber Inc New York

21 Cohen P (1978) Osteosarcoma of the long bones Clinical observations and ex *periences in the Netherlands* Eur J Cancer *14 995–1004*

22 Coley W B (1936) Diagnosis and treatment of bone sarcoma Glasgow Med J *126* 49–86

23 *Cortes, E Holland J Wang J & Sinks L (1972)* Doxorubicin in disseminated osteosarcoma JAMA *221* 1132–1138

24 Cortes E Holland J Wang J , Sinks L Blom J Senn H Bank A , & Glide well, O *(1974) Amputation and adriamycin in primary osteosarcoma N Eng J* Med *291* 998–1000

25 Cortes E Holland, J & Glidewell O (1978) Amputation and adriamycin in primary osteosarcoma *A five year report Cancer Treat Rep 62 271–277*

26 Dahlin D (1973) Bone tumors – general aspects and data on 3987 cases Charles C Thomas Springfield Illinois 2nd edn 3rd printing 156–175

27 Dahlin D & Coventry M (1967) Osteogenic *sarcoma A study of 600 cases* J Bone Jt Surg *49 A* 101–110

28 Dahlin, D (1975) Pathology of osteosarcoma Clin Orthop *111* 23–32

29 Dahlin D & Unni K (1977) Osteosarcoma of bone and its important recognizable varieties Am J Surg Pathol 61–72

30 De Santos L Murray J Finklestein B Spjut H & Ayala A (1978) The radio graphic spectrum of periosteal osteosarcoma Radiology *127* 123–129

31 Effendic S Cerasi E & Luft R (1974) Trauma hormonal factors with special reference to diabetes mellitus Acta anaest Scand *16* Suppl 55 107–119

32 Effendic S Cerasi E Elander I Thornqvist C Fick G Berglund, B & Luft R *(1979)* Studies on low insulin responders Acta Endocr *(Kbh) Suppl 224 5–32*

33 Eilber, F Townsend, C & Morton D (1975) Osteosarcoma Results of treatment employing adjuvant immunotherapy Clin Orthop *11* 94–100

34 Engell H C (1959) Cancer cells in the blood A five to nine year follow up study Ann of Surg *149* 457–461

35 Enneking W & Kagan A (1975) The implication of skip metastasis in osteo sarcoma Clin Orthop *111* 33–41

36 Enneking W & Springfield D (1977) Osteosarcoma Orthop Clin of N America *8* 785–803

37 Enneking W & Kagan A *(1978)* Transepiphyseal *extension of osteosarcoma –* incidence mechanism and implications Cancer *41* 1526–1537

38 Etcubanas E & Wilbur J (1978) Adjuvant chemotherapy for osteogenic sarcoma *Cancer Treat Rep 62 283–287*

39 Ewing J (1939) A review of the classification of bone tumours Surg Gyn & Obst *68* 971

40 Filipsson R (1975) A new method for assessment of dental maturity using the in dividual curve of number of erupted permanent teeth Ann Hum Biol *2 1* 13–24

41 Filipsson R & Hall K (1975) Prediction of adult height of girls from height and dental maturity at ages 6–10 years Ann Hum Biol *2 4 355–363*

42 Fisher D (1978) Osteosarcoma Advances in treatment or changing natural his tory Lancet *8* 82–82

43 Fitzgerald R Dahlin D & Sim F (1973) Multiple metachronous osteogenic sar coma J Bone Jt Surg *55–A* 595–605

44 Foss O Brennhovd I Messelt O Efskin J & Liverud K (1966) Invasion of tumour cells into the bloodstream caused by palpation or biopsy of the tumour Surgery *59* 691–695

45 Foster E & Shambaugh E (1964) Survival experience of patients with cancer of bone 1945–1959 Proc V Natl Cancer Conf J B Lippincott Co Philadelphia 385–396

46 Fraumeni J (1967) Stature and malignant tumors of bone in childhood and adolescence Cancer *20* 967–973

47 Frei E (1976) Methotrexate revisited Med Ped Oncol *2* 227–241

48 Frei E Jaffe N Skipper H & Gero M (1977) Adjuvant chemotherapy of osteogenic sarcoma – Progress and Perspectives In Adjuvant Therapy of Cancer Eds Salmon and Jones Elsevier N Holland Biomed Press Amsterdam 49–64

49 Friedman M & Carter S (1972) The therapy of osteogenic sarcoma Current status and thoughts for the future J Surg Oncol *4* 482–509

50 Gehan E (1978) Comparative clinical trials with historical controls a statistician s view Biomed Spec Issue *28* 13–19

51 Gilchrist G Ivins J Ritts R Pritchard D Taylor W & Edmonson J (1978) Adjuvant therapy for nonmetastatic osteogenic coma An evaluation of tran fer factor versus combination chemotherapy Cancer Treat Rep *62* 289–294

52 Goldman A Becker M Braunstein P Francis K Genieser N & Firooznia H (1975) Bone scanning-osteogenic sarcoma Correlation with surgical pathology Am J Roentgenol Rad Ther Nucl Med *124* 83–90

53 Goodman M McMaster J Drash A Diamond P Kappakas G & Scranton P (1978) Metabolic and endocrine alterations in osteosarcoma patients Cancer *42* 603–610

54 Hall K Takano K & Fryklund L (1974) Radioreceptor assay for somatomedin A J Clin Endocr *39* 973–976

55 Hall K Brandt J Enberg G & Fryklund L (1979) Immunoreactive somatomedin A i human serum J Clin Endocr *48* 271–278

56 Handelsman H & Carter S (1975) Current therapies in osteosarcoma Cancer Treatm Rev *2* 77–83

57 Holland J & Cortes E (1978) Surgical adjuvant chemotherapy in sarcomas Anti biot Chemother *24* 95–99

58 Hoover H Ketcham A Millar R & Gralnick H (1978) Osteosarcoma – Improved survival with anticoagulation and amputation Cancer *41* 2475–2480

59 Huang M Takita H & Douglass H (1978) Lung resection for metastatic osteogenic sarcoma J Surg Oncol *10* 179–182

60 Ikkos D & Luft R (1957) On the intravenous glucose tolerance test Acta Endocr (Kbh) *25* 312–334

61 Jaffe H (1958) Tumours and tumorous conditions of the bones and joints Lea & Febiger Philadelphia

62 Jaffe N (1972) Recent advances in the chemotherapy of metastatic osteog nic sarcoma Cancer *30* 1627–1631

63 Jaffe N (1976) Osteogenic sarcoma – State of the art with high-dose methotrexate treatment Clin Orthop *120* 95–102

64 Jaffe N Frei E Traggis, D & Bishop Y (1974) Adjuvant methotrexate and citrovorum factor treatment of osteogenic sarcoma N Engl J Med *291* 994–997

65 Jaffe, N Watts H Fellowes K & Vawter G (1978) Local en bloc resection for limb preservation Cancer Treat Rep *62* 217–223

66 Jaffe N Frei E Watts H & Traggis D (1978) High dose methotrexate in osteogenic sarcoma A five year experience Cancer Treat Rep *62* 259–264

67 Jeffree G Price C & Sissons H (1975) The metastatic patterns of osteosarcoma Br J Cancer *32* 87–107

68 Jenkin, R Allt W & Fitzpatrick P (1972) Osteosarcoma – an assessment of management with particular reference to primary irradiation and selective delayed amputation Cancer *30* 393–400

69 Jones S & Salmons S (1979) Adjuvant therapy of Cancer II Grune & Stratton New York 355–392

70 Kessler J (1971) Cancer and diabetes mellitus A review of the literature J Chron Dis *23* 579–600

71 Knox L (1922) The relationship of massage to metastasis in malignant tumors Ann Surg *75* 129–142

72 Kuehn P Tamoney H & Gossling H (1970) Iliac vein occlusion prior to amputation for sarcoma Cancer *26* 536–546

73 Lagergren C Lindbom Å & Soderberg G (1961) The blood vessels of osteogenic sarcoma Acta Radiol *55* 161–176

74 Larsson S & Lorentzon R (1974) The incidence of malignant primary bone tumors in relation to age sex and site – a study of osteogenic sarcoma chondrosarcoma and Ewing s sarcoma diagnosed in Sweden from 1958 to 1968 J Bone Jt Surg *56–B* 534–540

75 Larsson S Lorentzon R Wedren H & Boquist L (1978) Osteosarcoma a multifactorial clinical and histopathological study with special regard to therapy and survival Acta Orthop Scand *49* 571–581

76 Lee S & MacKenzie D (1964) Osteosarcoma – a study of the value of preoperative megavoltage radiotherapy Br J Surg *51* 252–274

77 Lee S (1975) Osteosarcoma A reconnaissance Clin Radiol *26* 5–25

78 Lewis R & Lotz M (1974) Medullary extension of osteosarcoma Implications for rational therapy Cancer *33* 371–375

79 Lichtenstein L (1952) Bone tumors C V Mosby Co S t Louis

80 Lindbom Å Soderberg G & Spjut H (1961) Osteosarcoma A review of 96 cases Acta Radiol *56* 1–9

81 Lockshin M & Higgins I (1968) Prognosis in osteogenic sarcoma Clin Orthop *58* 85–101

82 MacDonald I & Budd J (1943) Osteogenic sarcoma A modified nomenclature and review of 118 five year cures Surg Gyn & Obst *77* 413–421

83 McKenna R Schwinn C Soon K & Higinbotham N (1966) Sarcomata of the osteogenic series (osteosarcoma fibrosarcoma chondrosarcoma parosteal osteogenic sarcoma and sarcomata arising in abnormal bone) An analysis of 552 cases J Bone Jt Surg *48–A* 1–26

84 McMaster J Scranton P & Drash A (1975) Growth and hormone control mechanisms in osteosarcoma Evidence for a new therapeutic approach Clin Orthop *106* 366–376

85 Marcove R (1978) En bloc resections for osteogenic sarcoma Cancer Treat Rep *62* 225–231

86 Marcove R Mike V Hajek J Levin A & Hutter R (1970) Osteogenic sar coma und r th age of twenty-one A review of one hundred and forty five opera tive cases J Bone Jt Surg *52–A* 411–423

87 Marcove R Martini N & Rosen G (1975) The treatment of pulmonary metas tasis in osteogenic sarcoma Clin Orthop *111* 65–70

88 Marroum M Huvos A & Rosen G (1977) Pathologic aspects of chemotherapy response in the treatment of osteogenic sarcoma An analysis of two cases On cology *34* 273–280

89 Marsh M (1927) Tumor massage and metastases in mice J Cancer Res *11* 101–107

90 Muggia F & Lowe A (1978) Five years of adjuvant treatment of osteosarcoma – more questions than answers Cancer Treat Rep *62* 301–305

91 Muggia F Catane E Lee Y & Rosencweig M (1979) Factors responsible for therapeutic success in osteosarcoma A critical analysis of adjuvant trial results In Adjuvant therapy of cancer II Eds Jones S and Salmons S 383–390

92 Nélaton A (1860) Pathologie chirurgicale Quoted by Kolodny A Surg Gyn & Obst *44* Suppl 1 1927

93 Nilsonne U (1979) Local osteosarcoma reaction in interferon treated patients MS

94 O'Hara J Hutter R Foote F Miller T & Woodard H (1968) An analysis of thirty patients surviving longer than ten years after treatment for osteogenic sar coma J Bone Jt Surg *50–A* 335–354

95 Peterson L Janes J Kelly P & Pease G (1960) Isolation of osteogenic sarcoma cells from peripheral blood after biopsy – an experimental report and clinical note Proc Mayo Clinic *35* 443–447

96 Poppe E Liverud K & Efskin J (1968) Osteosarcoma Acta chir Scand *134* 549–556

97 Potdar G (1970) Osteogenic sarcoma J Postgrad Med *16* 142–148

98 Pratt Ch Shanks E Hustu O Rivera G Smith J & Kumar M (1977) Ad juvant multiple drug chemotherapy for osteosarcoma of the extremity Cancer *39* 51 57

99 Pratt Ch Riviera G Shanks E Kumar M Green A & George S (1978) Com bination chemotherapy for osteosarcoma Cancer Treat Rep *62* 251–257

100 Price C (1958) Primary bone forming tumours and their relationship to skeletal growth J Bone Jt Surg *40–B* 574–593

101 Price C (1961) Osteogenic sarcoma An analysis of survival and its relationship to histologic grading and structure J Bone Jt Surg *43–B* 300–313

102 Price C (1966) The prognosis of osteosarcoma – An analytical study Br J Radiol *39* 181–188

103 Price C & Jeffree G (1977) Incidence of bone sarcoma in SW England 1946–1974 in relation to age sex tumour site and histology Br J Cancer *36* 511–522

104 Pritchard D Finkel M & Reilly Jr C (1975) The etiology of osteosarcoma – a review of current considerations Clin Orthop *111* 14–22

105 Rab G Ivins J Childs D Cupps R & Pritchard D (1976) Elective whole lung irradiation in the treatment of osteogenic sarcoma Can er *38* 939–942

106 Rao R & Rao N (1977) Prognostic significance of the regional lymph nodes in osteosarcoma J Surg Oncol 9 123–130

107 Rao U Cheng A & Didolkar M (1978) Extraosseous osteogenic sarcoma Can cer *41* 1488–1496

108 Rees L & Ratcliffe J (1974) Ectopic hormone production by non-endocrine tu mours Clin Endocr *3*, 263–299

109 Roberts S Hengesh J McGrath R Valaitis J McGrew E & Cole W (1967) Prognostic significance of cancer cells in the circulating blood Am J Surg *113* 757–762

110 Rosen, G , Murphy M & Huvos, A (1976) Chemotherapy en bloc resection and prosthetic bone replacement in the treatment of osteogenic sarcoma Cancer *37* 1–11

111 Rosen, G Huvos A , Mosende C Beattie, E , Exelby P Capparos, B & Marcove R (1978) Chemotherapy and thoracotomy for metastatic osteogenic sarcoma Can cer *41* 841–849

112 Rosenberg S Chabner, B Young R Seipp, C , Levin A Costa J Hanson T Head G & Simon R (1979) Treatment of osteogenic sarcoma I Effect of ad juvant high dose methotrexate after amputation Cancer Treat Rep *63* 739–751

113 Rosenberg S Flye W , Coukle D Seipp C Levin A & Simon R (1970) Treat ment of osteogenic sarcoma II Aggressive resection of pulmonary metastases Can cer Treat Rep *63* 753–756

114 Rudenberg, H Levin A , Spitler L , Wybran J & Byers U (1974) The therapeu tic uses of transfer factor Hosp Prac *9* 95

115 Salmons S & Jones S Eds (1977) Adjuvant Therapy of Cancer Elsevier N Hol land Biomed Press Amsterdam

116 Salzer M Salzer-Kuntschnik M Zhuber K Price C Willert H Immenkamp M Matejovsky Z Groh P & Keyl W (1976) Therapie und Prognose des kind lichen Osteosarcoms Arch Orthop Unfall Chir *85* 279–287

117 Scarff R (1937) Proc Royal Soc Med London *30* 796–800

118 Schwinn C & McKenna R (1973) The biologic behavior of osteosarcoma Bone and soft tissue sarcomas Proc VII Natl Cancer Conf J B Lippincott Co , Phila delphia 925–939

119 Scranton P , DeCicco, F Totten R & Yunis, E (1975) Prognostic factors in osteosarcoma Cancer *36* 2179–2191

120 Scranton P McMaster J Kenny F & Foley, T (1975) Investigation of carbo- hydrate metabolism and somatomedin in osteosarcoma patients J Surg Oncol 7 403–409

121 Shah A Exelby, P Marcove, R Rosen G & Beattie E (1977) Thoracotomy as adjuvant to chemotherapy in metastatic osteogenic sarcoma J Ped Surg *12* 983–990

122 Simon R (1978) Clinical prognostic factors in osteosarcoma Cancer Treat Rep *62* 193–197

123 Smith G & Dawson W (1924) Egyptian Mummies Allen and Unwin London

124 Spanos P Payne W & Ivins J (1976) Pulmonary resection for metastatic osteo genic sarcoma J Bone Jt Surg *58–A* 624–628

125 Spratt J (1965) The rates of growth of skeletal sarcomas Cancer *18* 14–24

126 Stewart, W (1979) The interferon system Springer Verlag Wien New York

127 Strander H (1977) Interferons Antineoplastic drugs? Blut *35* 277–288

128 Strander H Cantell K Ingimarsson S Jacobsson P Å Nilsonne U & Soder berg, G (1977) Interferon treatment of osteogenic sarcoma – a clinical trial Con ference on Modulation of host immune resistance in the prevention or treatment of induced neoplasias 9–11 Dec 1974 Fogarty Int Center Proc US Govern ment Printing Office Washington D C *28* 377–381

129 Strander H Adamson U Aparisi T Brostrom L Å Cantell K Einhorn S Hall K Ingimarsson S Nilsonne U & Soderberg G (1979) Adjuvant interferon treatment of human osteosarcoma In Recent Results in Cancer Research *68* Springer Verlag 40–44

130 Sutow W (1976) Late metastases in osteosarcoma Lancet *17* 856

131 Sutow W Suit H & Martin R (1975) Bone tumours Cancer in children Ed Bloom Springer Verlag 200–241

132 Sutow W Sullivan M Fernbach D Cangir A & George S (1975) Adjuvant chemotherapy in primary treatment of osteogenic sarcoma Cancer *36* 1598–1602

133 Sutow W Gehan E Dyment P Vietti T & Miale T *(1978) Multidrug* ad juvant chemotherapy for osteosarcoma Interim report of the SW Oncology Group Studies Cancer Treat Rep 62 265–269

134 Sweetnam R (1968) Osteosarcoma Hunterian Lecture at the Royal College of Surgeons of England April 11th 1968

135 *Sweetnam R (1975)* The surgical management of primary osteosarcoma Clin Orthop 111 57–64

136 Sweetnam R Knowelden J & Seddon H (1971) Bone sarcoma treatment by irradiation amputation or a combination of the two Br Med J *2* 363–367

137 Taranger J (1976) The somatic development of children in a Swedish urban com munity – a prospective longitudinal study Thesis Gothenburg University Med School Sweden

138 Taylor *W* Ivins J Dahlin D & Pritchard D (1978) *Osteogenic sarcoma ex* perience at the Mayo Clin 1963–1974 Immunotherapy of Cancer *Present status* of trials in man Ed Terry W D and Windhorst D Raven Press New York

139 Taylor W Ivins J Dahlin D Edmonson J & *Pritchard D (1978)* Trends and variability in survival from osteosarcoma Mayo Clin Proc *53* 695–700

140 *Telander R* Pairolero P Pritchard D Sim F & *Gilchrist G (1978) Resection* of pulmonary metastatic osteogenic sarcoma in children Surgery *84* 335–341

141 *Tudway R (1953)* The place of external irradiation *in the* treatment of osteogenic sarcoma J Bone Jt Surg *35 B* 9–21

142 Turnbull R Kyle K Watson F & *Spratt J (1967)* Cancer of the colon the in fluence of the no-touch isolation *techn*ic on survival rates Ann Surg *166* 420–427

143 Tyzzer E (1913) Factors in the production *and* growth of tumor metastases J Med Res *28* 309–332

144 Unni K Dahlin D Beabout J & *Ivins J (1976)* Parosteal osteogenic sarcoma Cancer *37* 2466–2475

145 Unni K *Dahlin* D & Beabout J (1976) Periosteal osteogenic *sarcoma Cancer* *37* 2476–2485

146 Upshaw J McDonald J & Ghormley R (1949) Extension of primary neoplasms of bone to bone marrow Surg Gyn & Obst *89* 704–714

147 Weinfeld M & *Dudley H* (1962) Osteogenic sarcoma A follow-up study of the 94 cases observed at the Massachusetts General Hospital from 1920–1960 J Bone Jt Surg *44–A* 269–276

148 *Weiss* A Adams G Bradkin B *Pritchell P* & Moreno H (1978) Osteosar coma Clin Orthop *135* 137–147

149 West K Oakley E Sanders M & Rubinstein A (1976) Epidemiology of dia betes and its vascular complications Eds Keen H Pickup J C Talwalker C V

108 Rees L & Ratcliffe J (1974) Ectopic hormone production by non-endocrine tu mours Clin Endocr *3* 263–299
109 Roberts S Hengesh J, McGrath R, Valaitis J McGrew, E & Cole W (1967) Prognostic significance of cancer cells in the circulating blood Am J Surg *113* 757–762
110 Rosen G, Murphy, M & Huvos, A (1976) Chemotherapy en bloc resection and prosthetic bone replacement in the treatment of osteogenic sarcoma Cancer *37* 1–11
111 Rosen G Huvos A Mosende C Beattie, E Exelby P Capparos B & Marcove R (1978) Chemotherapy and thoracotomy for metastatic osteogenic sarcoma Cancer *41* 841–849
112 Rosenberg S Chabner B Young R Seipp C Levin A Costa J Hanson T Head G & Simon R (1979) Treatment of osteogenic sarcoma I Effect of adjuvant high dose methotrexate after amputation Cancer Treat Rep *63* 739–751
113 Rosenberg S Flye W Coukle D Seipp C Levin A & Simon R (1970) Treatment of osteogenic sarcoma II Aggressive resection of pulmonary metastases Cancer Treat Rep *63* 753–756
114 Rudenberg H Levin A Spitler L Wybran J & Byers U (1974) The therapeutic uses of transfer factor Hosp Prac *9* 95
115 *Salmons S & Jones S Eds (1977) Adjuvant Therapy of Cancer* Elsevier N Holland Biomed Press Amsterdam
116 Salzer M Salzer-Kuntschnik M Zhuber K Price C Willert H Immenkamp M Matejovsky Z Groh P & Keyl, W (1976) Therapie und Prognose des kindlichen Osteosarcoms Arch Orthop Unfall Chir *85*, 279–287
117 Scarff R (1937) Proc Royal Soc Med London *30* 796–800
118 Schwinn, C & McKenna R (1973) The biologic behavior of osteosarcoma Bone and soft tissue sarcomas Proc VII Natl Cancer Conf J B Lippincott Co Philadelphia 925–939
119 Scranton, P, DeCicco, F Totten R & Yunis, E (1975) Prognostic factors in osteosarcoma Cancer *36*, *2179–2191*
120 Scranton P McMaster J Kenny, F & Foley T (1975) Investigation of carbohydrate metabolism and somatomedin in osteosarcoma patients *J Surg Oncol 7* 403–409
121 Shah A Exelby P Marcove R Rosen G & Beattie E (1977) Thoracotomy as adjuvant to chemotherapy in metastatic osteogenic sarcoma J Ped Surg *12* 983–990
122 *Simon R (1978) Clinical prognostic factors in osteosarcoma* Cancer Treat Rep *62* 193–197
123 Smith G & Dawson W (1924) Egyptian Mummies Allen and Unwin London
124 Spanos P Payne W & Ivins J (1976) Pulmonary resection for metastatic osteogenic sarcoma J Bone Jt Surg *58–A* 624–628
125 Spratt J (1965) The rates of growth of skeletal sarcomas Cancer *18* 14–24
126 Stewart W (1979) The interferon system *Springer Verlag Wien New York*
127 Strander H (1977) Interferons Antineoplastic drugs? Blut *35* 277–288
128 Strander H Cantell K Ingimarsson S Jacobsson P Å Nilsonne U & Soderberg G (1977) Interferon treatment of osteogenic sarcoma – a clinical trial Conference on Modulation of host immune resistance in the prevention or treatment of induced neoplasias 9–11 Dec 1974 Fogarty Int Center *Proc* US Government Printing Office Washington *D C 28* 377–381

Proceedings of Satellite Meeting of IX International Diabetes Federation Meeting Bombay, 27
150 Yaghmai I (1977) Angiographic features of osteosarcoma Am J Roentgenol *129* 1073–1081

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A retrospective study of 869 cases reported to the Finnish Cancer Registry between 1962 and 1968

BY

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CONTENTS

1 INTRODUCTION

Primary malignant bone tumours have been known for thousands of years Archaeological research shows that the Egyptians were familiar with them already at the time of the building of the pyramids (see Christensen 1925 Ott et al 1977) The study and diagnosis of bone tumours has continued right up to our own time As far as one can tell from the literature on the subject the first person to describe a primary malignant bone tumour was Dalrymple who in 1846 diagnosed myeloma nodules or *mollities ossium* (see Carson et al 1955) Bence-Jones discovered that the urine of myeloma patients secreted thermolabile albumin The clinical details of myeloma were described by McIntyre in 1850 (see Lumb et al 1948) Virchof diagnosed chordoma in 1857 (see Spjut et al 1964) and in 1922 Beck observed the carcinogenic effect on bone of ionising radiation In the same year James Ewing published a study of diffuse endothelioma of the bone a disease that differed from both osteo-sarcoma and myeloma and which is now known as Ewing s sarcoma In 1928 and 1930 respectively Oberling discovered reticulum cell sarcoma and Phemister chondro-sarcoma diseases that now bear their names In 1943 Budd and MacDonald diagnosed fibro sarcoma Parosteal osteo sarcoma was discovered in 1951 (Gesichic ter and Copeland) and lipo-sarcoma in 1955 (Dawson) Primary malignant fibrous histio-cytoma of the bone was first mentioned in 1975 (Spanier et al)

Primary malignant bone tumours have been a constant object of scientific study As a result of developments in surgery new techniques like extensive bone trans plants and bio mechanical prostheses have made it possible to treat patients without disabling them to the same extent as heretofore Developing radiation treatment and in recent years particularly cytostat treatment as well as immunological treat ment which is still at the experimental stage have provided new possibilities for helping patients with bone tumours

Table 1 Studies dealing with primary malignant bone tumours 19 5—1972

Christensen (1925)	1 000 cases
Cambell (1934)	250
Poppe (1949)	20
Prevo (1950)	205
Hoppe et al (195?)	31
Coventry et al (1957)	430
Platt (1962)	256
Aakhus et al (1963)	71
Hendersson et al (1963)	288
Phillips (1965)	8?7
Copeland (1967)	700
Dahlin et al (1967)	600
Falk et al (1967)	940
Dahlin (1972)	2 962

In Finland primary malignant bone tumours have been studied by the follow-

ing investigators among others F Langenskiold (1929) Mustakallio (1937, 1947) Roukkula (1959) Tala and Koikkalainen mio (1969), Koskinen (1967, 1968 1972 1973 1978, 1979) and Paavolainen and Teppo (1976)

2 SURVEY OF LITERATURE

2 1 INCIDENCE

According to the information provided by cancer registries in different countries primary malignant bone tumours are rare They account for approximately two per cent of all malignant tumours in man Since the weight of the human skeleton is about 20 % of the whole body (Rauber-Kopsch 1958) it might be expected that there would be a higher frequency of bone tumours The 10^5 incidence rate per inhabitant varies in different countries from 0 7 to 4 0 (Hoppe et al 1952 The Swedish Cancer Registry 1960 The Cancer Registry of Norway 1964 Copeland 1967 Robertsson et al 1967 Boyd et al 1969 Bristol Bone Tumour Registry 1971 Teppo et al 1972 Ott et al 1977) The lack of national registries outside Scandinavia makes it difficult to get precise information

The occurrence of malignant bone tumours may vary geographically within the same country Thus in South Africa bone tumours and connective tissue tumours are less common in the Johannesburg region than elsewhere (Robertson et al 1967) Paget s disease and the bone sarcoma that results from it are common in Great Britain but rare in Norway Greece Japan and the United States (Price et al 1962 Lochkin et al 1963) Paget s disease is most widespread in Great Britain (Price et al 1962)

2 2 HISTO PATHOLOGICAL CLASSIFICATION

The present histo-pathological classification of bone tumours is the outcome of prolonged research The classification published by the World Health Organization (Schajowicz et al) in 1972 is based on clinical radiological and histo-pathological research Table 2

Table 2 Histological classification of primary malignant bone tumours (Schajowicz et al WHO 1972)

Bone forming tumours
Osteo-sarcoma
Parosteal osteo-sarcoma
Cartilage forming tumours
Chondro-sarcoma
Juxta cortical chondro-sarcoma
Mesenchymal chondro-sarcoma
Giant-cell tumours
Malignant giant-cell tumour
Bone marrow tumours
Ewing s sarcoma
Reticulum-cell sarcoma
Lympho-sarcoma
Myeloma
Vascular tumours
Angio-sarcoma
Other connective tissue tumours
Fibro-sarcoma
Lipo-sarcoma
Malignant mesenchymoma
Undifferentiated sarcoma
Other tumours
Chordoma
Adamantinoma of long bones
Neuro-sarcoma

In Finland, it is planned to add the following categories in the clinical classification of tumours secondary chondrosarcoma the sub-groups of myeloma — solitary myeloma and multiple myeloma, extra-medullary plasma-cytoma and the sub-groups IgA IgG and IgM, also haemangio-endothelioma-sarcoma haemangio-pericytoma-sarcoma, radiation sarcoma primary malignant fibrous histiocytoma, NUD sarcoma, fibrolipo-myxoma malignum chondro-myxoma malignum and fibro-myxoma malignum (Sorvari, 1976)

2 3 ETIOLOGY

It has been shown that genetic factors are involved in primary malignant tumours occurring in Ollier's disease and in hereditary multiple chondromatosis (Mainzer et al 1971 Lichtenstein 1972) Among patients suffering from the last-mentioned disease chondro-sarcoma occurs in 25 % (Solomon 1974) (Marcove 1977)

In osteo-genesis imperfecta spontaneous fractures are common and it might be supposed that there would be a high frequency of sarcoma resulting from abundant callus formation This however is not the case and sarcoma of the bone is in fact rare though individual cases have been reported (Koskinen 1958 Klenerman et al 1967)

Malignant giant-cell tumours are preceded by benign giant-cell tumours (Sabanas et al 1956 Copeland et al 1967)

In Gardner s syndrome where the patient has carcinoma of the colon and sarcoma of the bone the malignancy develops in a polyp in the colon and in the bone by way of a fibrous dysplasia (Johnson et al 1972)

In Paget s disease the probability that malignancy will develop is 0 7 % — 3 0 % per year (Esposito et al 1960 MacKenzie et al 1961, Dahlin et al 1967, Folsch 1968 Price et al 1969)

The development of malignancy in fibrous dysplasia was described by Coley and Stewart in 1945 Their study revealed that those patients in whom malignant fibrous dysplasia developed had undergone radiation treatment for the bone lesion in question Radiation treatment has also often been given for Paget s disease (Tanner et al 1961 Dahlin et al 1967)

Chronic osteitis has been considered an etiological factor in the development of malignant bone tumours Streptococcus cavitae found in a fistula has been considered an irritant that causes malignancy (Lacassagne et al 1928) The incidence of malignancy in fistulating osteitis is 0 23 % per year (Poprikov 1968)

It has been shown that radiation, particularly in connection with tubercular inflammation causes malignant bone tumours (Marie et al 1910 Cahan et al 1948) It has been found that patients who have had radiation treatment and people exposed to radiation in industrial work are more liable than others to get malignant bone tumours (Cade 1955 Mindell et al 1977) In females treated for breast cancer with a dose of 4 000 rad there is a probability of 0 07 % — 0 22 % that malignant bone tumours will develop (Schwartz 1968 Hatfield 1970)

It has been found in experiments with animals that osteo-sarcoma can just as well be caused by a single dose of radiation as by repeated doses (Sabanas et al 1956 Steiner 1965 Arlen et al 1971 Yamanato 1971 Mindell et al 1977 Ott et al 1977) The latency time is long and it is typical that during this time the organ

in question is symptom free The younger the patient and the larger the dose the greater is the risk of radiation sarcoma (Mindell et al. 1977) Radiation sarcoma is often caused by radiation treatment given for a benign bone lesion (Arlen et al 1971) Radiation affecting the whole body has seldom been shown to cause bone tumours the radiation dose necessary to induce sarcoma must be large and in the cases studied the doses were usually fatal (Yamamoto 1971)

It has not been possible to demonstrate to what extent trauma may be an etiological factor in the development of primary malignant bone tumours although some investigators are of the opinion that trauma may partly explain the greater frequency in males of such tumours (Ewing 1935 Phemister 1948 Cade 1955 Krebs et al 1963 Hellner 1966 Voutilainen et al 1967 Fisher 1971) It has been observed that sarcoma in the metaphysis sometimes penetrates all tissues but stops short at the epiphyseal line a suggested explanation is that the greater amount of growth hormone in the epiphyseal part prevents the development of osteo-sarcoma (Krebs 1962)

2 4 AGE DISTRIBUTION

There are two periods in the course of life when the risk of primary malignant bone tumour is great Ewing s sarcoma tends to occur especially between the ages of 11 and 13 and osteo sarcoma between 16 and 18 (Price et al 1975) Chondro sarcoma and myeloma occur most frequently between the ages of 55 and 60 (Coley et al 1938 Prevo 1950 Hoppe et al 1952 Cade 1955 Compere 1964 Lodwick 1964 Ranke 1968 Dahlin 1972) Children account for approximately 20 % of all patients suffering from primary malignant bone tumours (Dedo 1971 Grover et al. 1972 Welte et al 1974) Children and young adults are more likely than people of middle age or old people to suffer from primary malignant bone tumours (Coley et al 1938) Welte (1974) described a series of 109 children suffering from malignant tumours and of these 13 % had primary bone tumours

2 5 RACE

Except for Ewing s sarcoma which occurs more among white people (see Bethge 1953) race does not appear to be a factor in the incidence of bone tumours

2 6 SEX

Primary malignant bone tumours are on the whole found more frequently in males than in females (Christensen 1925 Phemister 1948 Glenchur et al 1959 Price 1962 Foster et al 1964 Phillips 1965 Dahlin et al 1967)

2 7 LOCATION

Location is presented in Table 3

Bone sarcomas are most often located in the metaphysis of long bones Chondrosarcoma is often also found in the pelvis and ribs Malignant giant-cell tumours are most frequently situated in the region of the knee in the humerus and in the distal metaphysis and epiphysis of the radius tibia and fibula (Dahlin 1972) Parosteal osteo-sarcoma and parosteal chondro-sarcoma are located juxta-cortically Ind vid-

Table 3 Location of primary malignant bone tumours (Coley et al 1950 Wang et al 1953 Bethge 1953 Sherman et al 1956 Coventry et al 1957 Henderson et al 1963 Dahlin 1972 Spanier et al 1975)

	Long bones	Pelvis Rib	Skull	Spine
Bone-forming tumours				
Osteo-sarcoma	++++	++	++	++
Parosteal osteo-sarcoma	++++	+	+	+
Cartilage-forming tumours				
Primary chondro-sarcoma	++++	++++	+	++
Secondary chondro sarcoma	++++	++++	+	+
Parosteal chondro sarcoma	++++	++++	+	+
Mesenchymal chondro-sarcoma	++++	++++	+	+
Giant-cell tumours				
Malignant giant-cell tumour	++++	+	+	+
Bone marrow tumours				
Ewing s sarcoma	++++	++	++	+
Reticulum cell sarcoma	+++	++	++	+++
Lympho-sarcoma	+++	+	+	++
Myeloma	++++	++++	++++	++++
Vascular tumours				
Angio sarcoma	++++	++	+	+
Haemangio-endotelioma sarcoma	++++	++	+	+
Haemangio pericytoma sarcoma	++++	++	+	+
Other connective-tissue tumours				
Fibro-sarcoma	++++	+++	+	+
Lipo-sarcoma	++++	++	+	+
Malignant mesenchymoma	++++	++	+	+
Primary malignant fibrous histio cytoma	++++	+	+	+
Undifferentiated sarcoma	++++	++	++	++
Radiation sarcoma	++++	+++	++	++
Other tumours				
Chordoma	—	—	—	++++
Adamantinoma of long bones	++++	—	—	—
Neuro-sarcoma	++++	+	+	+

ual cases of osteo-sarcoma in the soft tissues have been reported (Fine et al 1956 Dahlin 1972)

Myelomas are typical in the diaphysis of the long bones in the spine the skull the pelvis and the ribs (Dahlin 1972) 75 % of extra-medullary plasma-cytomas are situated in the region of the upper respiratory passages (Wiltshaw 1976) most frequently in the hypo-pharynx the nose the clavicular recess or neck glands and occasionally in the orbit thyroid gland or abdominal cavity (Rodman et al 1968 Oberkircher et al 1972 Sasse et al 1973)

Chordomas are always located in the region of the spine generally in the fora-

men magnum or in the sacrum (Dahlin 1972) Adamantinomas of long bones are always found in the diaphysis

90 % of all primary malignant bone tumours in the thorax are situated in the ribs (Teilbaum 1972)

2 8 SYMPTOMS AND DIAGNOSIS

2 8 1 Pain

Local pain is often the first symptom of a primary malignant bone tumour (Coley et al 1938 Aakhus et al 1963 Dahlin 1972) Severe pain felt especially in a joint means that the tumour is continuously growing (Dahlin 1972) The tumour is situated where the pain is felt except when the tumour causes radicular pains (Copeland 1967) Different tumours cause different kinds of pain It is typical of malignant giant-cell tumours that they cause slight intermittent pain (Murphy et al 1956) If a benign giant-cell tumour begins to cause pain this is always a pathognomonic symptom (Dahlin 1972) 80 % of myeloma patients have pains in the bone (Glenchur et al 1959) These pains are often radicular and accompanied by parestesias

2 8 2 Resistance to palpation

Resistance to palpation combined with a flushing and reddening of the skin are typical features of an advanced tumour (Dahlin 1972) If the tumour is not attached to the cortex of the bone tenderness is the only observable feature (Dahlin 1972) It is typical of parosteal tumours that they are palpable are attached to the surrounding tissue and feel diffuse (Dwinnel et al 1954) It has been ascertained that in 80 % of patients suffering from malignant giant-cell tumours there is a hard crepitating resistance to palpation (Williams et al 1964) In myeloma patients it has been found that 20 % showed resistance to palpation in the ribs clavicle or skull (Glenchur et al 1959)

It is usually possible to confirm chordoma of the sacrum and also tumours of the pelvis by palpation per rectum An extra medullary plasma-cytoma can be felt in situ (Dahlin 1972)

2 8 3 Decreased activity

Limitation of movement and a tendency to become easily fatigued are signs of a rapidly advancing tumour (Dahlin 1972) In chordoma of the sacrum, common symptoms connected with the paresis caused by compression of the sacral roots of the spinal cord are constipation sciatic pain and numbness of the buttocks (Dahlin 1972)

2 8 4 Pathological fracture

50 % of myeloma patients have a pathological fracture at some stage of the disease (Carson et al 1955 Glenchur et al 1959) and 10 % have paraplegia resulting from the pathological fracture of a vertebra when they first present themselves for treatment (Lumb et al 1948 Ulrich e al 1958) Pathological fracture has been certified in 5 % of sarcoma patients (Banshali et al 1963) and in 6 % of chondrosarcoma patients (Copeland 1967) when they first presented themselves for treatment

2 8 5 Decline in general health

A typical symptom of a far advanced malignant bone tumour is a decline in

Table 3 Location of primary malignant bone tumours (Coley et al 1950 Wang et al 1953 Bethge 1953 Sherman et al 1956 *Coventry et al 1957 Henderson et al* 1963 Dahlin 1972 Spanier et al 1975)

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2 8.5 Decline in general health

A typical symptom of a far advanced malignant bone tumour is a decline in

general health 50 % of myeloma patients have symptoms of this kind when they come for treatment (Glenchur et al 1959)

2 8 6 Trauma

In earlier literature a trauma reported by the patient has been considered an etiological factor contributing to the development of a primary malignant bone tumour (Krebs et al 1963) It has not, however, been possible to define either the mechanism of injury or the severity of the trauma with sufficient exactitude to decide whether or not it was really an etiological factor 75 % of bone sarcoma patients report trauma and symptoms resulting from it (Derian et al 1968) Present-day investigators consider trauma to be an unlikely etiological factor (Hellner 1966 Copeland 1967 van der Heul et al 1967 Fisher 1971) An attempt has been made by means of tissue cultures to determine the part played by trauma but this was not successful (Krebs et al 1963) Trauma may cause secondary spreading of the disease by releasing malignant cells into the blood stream and lymphatic ducts, and also haematoma by means of resorption Tissue pressure increases the development of metastases and extravasion (Krebs et al 1963) A developing tumour may cause symptoms similar to those in trauma (Phemister 1948)

2 8 7 Lack of symptoms

About one per cent of patients suffering from primary malignant bone tumours are symptom-free at the moment of diagnosis Extramedullary plasma-cytoma is sometimes discovered by chance when the nose and throat are being examined (Dahlin 1972)

2 8 8 Duration of symptoms

The symptoms of primary malignant bone tumours usually last about 1—3 months before they are diagnosed Exceptions are chondro-sarcoma for which symptoms may last 11—12 months before diagnosis and parosteal osteo-sarcoma the symptoms of which may go on for years (O Neal et al 1952)

2 9 X-RAY EXAMINATIONS

2 9 1 Plain radiography

Radiological diagnosis of primary malignant bone tumours is difficult (Gold 1975) The most important method of examination is plain radiography, by means of which 90 % of bone tumours can be revealed (Lodwick 1964, Ranke 1968)

In diagnosing bone tumours by X ray the following factors are taken into account the radiological location of the tumour its structure and its relationship to the surrounding tissue (Ranke 1968 Dedo 1971)

With the help of a computer it is usually possible by analysing the X rays to make a histo-pathological diagnosis of the bone tumour before starting treatment (Lodwick 1964 Lodwick et al 1965 1970 Virtama et al 1979) It is possible in this way to provide the patient with the best possible treatment

2 9 2 Angiography

Angiography is an important X ray technique for diagnosing bone tumours i gives a good idea of the size and location of the tumour its relationship to the surrounding tissue its haemodynamics and its rapidity of growth (Kittredge et al

1970 Honcomp et al 1973 Gold 1975 Jacob 1976) Angiography is no substitute for biopsy in making a histo-pathological diagnosis (Gold 1975) but is often a great help in deciding where to take the biopsy sample from (Jacobs 1976) The significance of angiography does not lie in its diagnostic value but rather in the planning of treatment (Virtama 1979) About 25 % of angiographies have diagnostic value (Voegeli et al 1976) Angiography provides valuable additional information about the degree of malignancy of the tumour the development of secondary malignancy the probability of recurrence possibility of treatment and checking the progress of the disease (Koskinen et al 1968 Yagmai et al 1971 Honkomp et al 1973)

2 9 3 Lymphography

Lymphography is a method that has not been much used for determining the degree of spreading of primary malignant bone tumours In a dissertation published in 1976 Tallroth found that the spreading of a tumour into the lymphatic ducts could be determined by means of lymphography in 100 % of reticulum cell sarcomas in 57 % of osteo sarcomas and in 50 % of Ewing s sarcomas In cases where the tumour has spread into the lymphatic ducts it is especially important to think carefully before embarking on any far reaching treatment of the primary tumour (Herzog 1972 Rao et al 1977) Bone tumour metastases in the lymphatic ducts are more common than was earlier thought (Macintosh et al 1975)

2 9 4 Other examinations

The advantage of scintigraphy over many other radiological methods for studying bone tumours is that it is less exhausting for the patient It is also cheap Nowadays pyrophosphates polyphosphates and diphosphonates labelled Tecnetium 99 m are much used in bone scintigraphy The scan is compatible with X ray findings in 75 % of cases (Holsti et al 1967 Tong et al 1968 Nordman et al 1977) Scintigraphy does sometimes give incorrect positive findings but generally the strong tracer uptake correlates with the high degree of bone destruction (Aho et al 1973) The following are some of the advantages of scintigraphy (McCormack 1975 Nordman et al 1977)

- it is indicated in all examinations for the degree of spreading of bone tumours
- identification of primary focus is earlier than with other X-ray examinations
- it makes possible determination of polyostotic changes
- it makes possible determination of early and late as well as skip metastases in the medulla
- it provides the possibility of following the effects of treatment
- it provides the possibility of using radiopharmaceutical drugs especially for myeloma
- it determines what other X ray examinations are necessary

In cases where the tumour is known to be polyostotic scintigraphy of the whole body is indicated For example 30 % of chordomas and Ewing s sarcomas are polyostotic (McCormack 1975)

Tomography is significant for the differential diagnosis of inflammation and can reveal possible sequesters Computer tomography gives a good idea of the spread of the tumour into the bone mar

row and the metastases therein (de Santos et al 1978 Virtama 1979)

Some investigators have made use of thermography for studying primary bone tumours, but its precise significance is not yet clear (Farrell et al 1971)

2 10 LABORATORY STUDIES

2 10 1 General

Laboratory studies are important in the diagnosis of primary malignant bone tumours and also for determining the degree of spreading of the tumour In sarcoma patients with a far advanced tumour there is usually an elevated erythrocyte sedimentation rate reduced Hb and pathological alkaline phosphatase It is possible by studying the large enzymes to distinguish between alkaline phosphatase originating in the bones and that which stems from the liver The elevated level of alkaline phosphatase originating in the bones which occurs in sarcomas arising from Paget s disease returns to normal when the tumour is removed (McKenna et al 1964) It is also possible by means of laboratory tests to follow the results of treatment (O Hara et al 1968 Folsch 1968 Derian et al 1972)

2 10 2 Laboratory diagnosis of myeloma

The earliest laboratory findings concerning myeloma were made in the last century Bence-Jones discovered in 1845 that myeloma patients had albumin in their urine and he later isolated what is known as Bence-Jones proteinuria If electrophoresis and a precipitation reaction are used it is possible to confirm Bence-Jones proteinuria in 85 % of myeloma patients (Carson et al 1955, Martinez-Maldonado et al 1971) At the moment of diagnosis 60 % of myeloma patients have an erythrocyte sedimentation rate of more than 50 mm/t and Hb less than 120 g/l (Carson et al 1955 Leawell et al 1966) Leukopenia occurs in 60 % and leukocytosis in 20 % of myeloma patients (Lumb 1948) More than half of these patients suffer from pathological lympho-cytosis One third of myeloma patients have a pathological number of plasma cells in the peripheral blood (Glenchur et al 1959 Drivsholm 1965)

In 80 % of myeloma patients plasma albumin is as high as 80 g/l and more (Lumb et al 1948, Drivsholm 1965) 20 % —40 % of myeloma patients have hypercalcemia (Carson et al 1955) Alkaline phosphatase is elevated in 30 % of myeloma patients (Esposito et al 1960) whereas in Paget s disease it is elevated in over 95 % of patients (Leawell et al 1966 Drivsholm 1965)

Electrophoresis and immuno-electrophoresis are important methods for studying serum immunoglobulins By electrophoretic means it is possible to make pathological and diagnostic findings in the serum of 90 % of myeloma patients (Drivsholm 1965 Leawell et al 1966) Immunoglobulins are usually of the IgG type IgA cases are less than half as numerous as IgG The IgM type accounts for less than one per cent of cases (Leawell et al 1966) Only three cases of the IgE type have been reported in literature (Wasastjarna 1974) Biclonal myeloma containing two M components is rare (Wasastjarna 1974)

Bence-Jones proteinuria is found in the urine of 16 % of myeloma patients with normal electrophoresis In studying the electrophoresis of serum and urine a diagnostic result is achieved in 93 % of cases

(Leawell et al 1966) A similar finding has been made by Azar (1972) among others

Ten per cent of myeloma patients suffer from amyloidosis when they come for treatment (Carson et al 1955) The cause of amyloidosis is the sensitivity of tissue to paraproteins (Carson et al 1955 Mar tinez Maldonado et al 1971) In myeloma patients it is amyloidosis that is the prin cipal cause of renal insufficiency Renal function is impaired in 40 % of myeloma patients (Drivsholm 1965)

Bone marrow tests give positive diag nostic results in 80 % of myeloma cases (Drivsholm 1965 Leawell et al 1966)

2 11 HISTO PATHOLOGICAL EXAMINATIONS

Because of the quality of the tissue to be studied histo pathological examination of bones may be difficult Moreover bone tumours are rare and the result is that very few pathologists are experts in the histo pathology of bones It is neverthe less necessary to have histo pathological confirmation before bone tumours can be treated clinically If a benign bon lesion is diagnosed as a malignant tumour the treatment given may involve irreversible loss and on the other hand to diagnose a malignant tumour as benign will be fatal for the patient (Copeland 1967)

In order to be reliable pre-operative biopsy must be performed as open biopsy (Hajdu et al 1971) Some investigators think there is a risk that open biopsy may cause metastases to develop

Some people favour the use of needle biopsy (Schajowicz et al 1968 Hajdu et al 1971 1975) For giant cell tumours it is an untrustworthy method (Williams et al 1964) Biopsy means a less favourable prognosis (Lindbom et al 1961) and needle biopsy does not generally lead to a clear diagnosis (Aakhus et al 1963) Study of frozen sections is difficult for the patho- logist Some investigators consider that the accuracy of such a study is not greater than 30 %—75 % (Derian et al 1968) Copeland (1967) expressed the following thought about the study of frozen sections and this we may consider realistic » it is valuable for an experienced pathologist but measures like amputation should never be undertaken without first doing a par- affin examination

2 12 DIAGNOSIS

2 12 1 General

The possibility of primary malignant bone tumour is not always taken into ac count and this is one reason why diagnosis is sometimes difficult (Dissing et al 1977 Salenius 1978) The patient is treated on the basis of an incorrect diagnosis for example dislocation of a joint bruising anaemia kidney disease or fever (Dissing et al 1977) Diagnosis of bone tumours must be based on the results of clinical tests — radiography laboratory and histo- pathological study — and a synthesis of the findings (Cade 1955 Compere 1964 Hellner 1966 Copeland 1967 Koskinen 1976 Sissons 1977 Compere 1978)

2 12 2 Differential diagnosis

In osteogenesis imperfecta hyperplastic callus simulates osteo sarcoma (Baker 1967) In connection with trauma myositis ossificans resembles a bone tumour and is sometimes difficult to distinguish from osteo-sarcoma Furthermore if there is a

slight trauma the bruises may make diagnosis more difficult (Banshali et al 1963) Stress fracture and low-grade osteo-myelitis in which there is slight periostitis resembles inflammatory osteo-sarcoma (Hellner 1966, Orava et al 1978) In differential diagnosis, the progress of the disease and the failure of anti-biotics to take effect are important factors (Hellner 1966) Bouts of slight fever, elevated erythrocyte sedimentation rate, leucocytosis and serological findings are not conclusive (Hladik et al 1967) Even in biopsy, it is difficult to distinguish between Ewing s sarcoma and osteo-myelitis (Banshali et al 1963 Hellner 1966) Benign bone lesions are frequently misdiagnosed as malignant, especially in children A misdiagnosis, either in children or adults may have tragic consequences (Copeland 1964)

2 13 TREATMENT

2 13 1 General

There are many different ideas about how to treat primary malignant bone tumours (Ranke 1962) Because treatment of bone tumours often severely disables the patient or leads to death the great problem is how to plan the treatment (Compere 1964) It is the histological diagnosis of bone tumours that finally decides the treatment to be given (Reichmann 1976 Aho 1979) Recent improvements have made it possible to make a correct histological diagnosis pre-operatively and this has made it easier to choose the correct treatment

2 13 2 Radical ablative surgery

Until recently the treatment for primary malignant bone tumour has been radical ablative surgery (Copeland 1967, Dahlin 1972) The general belief has been that other forms of treatment are ineffective (Coventry et al 1957, Nilsonne 1965 Copeland 1967, Wagner et al 1967) According to Compere (1964)) only 10 % of patients treated with ablative surgery have been cured The traumatic effect of ablative surgery can only be minimized by maximizing medical, surgical, pathological and psychological knowledge (Enelow 1975) In individual cases a permanent cure has been effected by super radical ablative surgery — hemipelvectomy and hemicorporectomy (Higinsbotham et al 1956 Pack 1956 Koskinen 1967 Franklin et al 1977, Miller 1977 Sneppen et al 1978) but there is no difference in the five-year survival rates (Foster et al 1964) Although radical ablative surgery is by no means always curative it has been reported that it definitelv slows down the develop ment of metastases and thus prolongs the patient s life (Nilsonne 1965) If the tumour recurs in the stump of an amputated limb this means that the surgery was not radical (Dahlin et al 1967)

2 13 3 Radical resection

In the treatment of malignant bone tumours the method of radical resection has developed considerably in recent years The resected bone is replaced by an autogenic bone an allograft or a prosthesis A vascular bone transplant is possible in special cases (Weiland et al 1978) A precondition for the success of radical resection is that the tumour can be removed in its entirety The method is best suited for parosteal osteo-sarcoma of the long bones chondro sarcoma giant cell tumours and in special cases fibro-sarcoma (Volkov 1970 Parrish 1972 Ottolenghi 1973 Wil-

son 1975 Burrows et al 1975 Meyers 1977 Smith et al 1977 Koskinen 1978 Koskinen et al 1979)

2 13 4 Local resection

In local resection the distance between the tumour and the resection line is less than five centimetres The smaller the distance the greater is the possibility that tumour cells will remain behind Local resection has proved to be a successful method especially in treating chondrosarcoma in small bones and also giant cell tumours Local resection has also been used rather often in the past in the treatment of sarcoma of long bones Early results for patients treated in this way were often good but recurrence of the tumour or metastases developed rapidly In the series reported by Lindbom (1961) recurrence of tumour or development of metastases was very rapid

2 13.5 Local evacuation

Neither local evacuation abrasion nor electro coagulation are acceptable methods of treatment for any kind of malignant bone tumour When giant-cell tumours have been treated in this way it has led to the paradoxical response described by Herenden (see Murphy et al 1956) in which the malignancy of the tumour is increased

2 13 6 Palliative surgery

Palliative surgery in which some tumour tissue is knowingly left in place is sometimes necessary in treating a bone tumour patient in order to dispel severe pain or relieve the necrotization of the tumour (Cade 1955)

Palliative surgical treatment of metastases has in individual cases led to good results even with a ten year follow up and longer (Francis et al 1962 Dahlin et al. 1967 Tala et al 1967 Sellors 1970 Scanlon 1972 Holmes et al 1977) In the treatment of all malignancies it has been found that the patient s own resistance is longer if the greater part of the tumour is removed or destroyed (Reichmann 1976)

2 13 7 Radiation treatment

Primary malignant bone tumours can be classified as sensitive to radiation moderately sensitive to radiation and resistant to radiation (Table 4) Radiation treatment has a clear effect on tumours that are sensitive to it and the significance of radiation treatment has increased in recent years (Cade 1955 Aakhus et al 1963 Heilmann 1971 Holsti et al 1977)

Radiation treatment is of very little use in the treatment of bone and cartilage-forming tumours neither is it of much value for malignant giant cell tumours Bone marrow tumours react well to radiation treatment Radiation treatment is an important part of therapy for Ewing s sarcoma and is the main form of treatment for reticulum cell sarcoma and lympho sarcoma Reticulum-cell sarcoma and lympho sarcoma are curable by radiation and mutilating ablative surgery is contra indicated in the treatment of these tumours (von Ronnen et al 1974 Nordman 1979)

Vascular tumours connective tissue tumours and other malignant bone tumours are generally somewhat sensitive to radiation (Table 4)

In recent years the significance of preoperative radiation treatment has declined considerably owing to the increase in bone

slight trauma the bruises may make diagnosis more difficult (Banshali et al 1963) Stress fracture and low-grade osteo-myelitis in which there is slight periostitis resembles inflammatory osteo-sarcoma (Hellner 1966, Orava et al 1978) In differential diagnosis, the progress of the disease and the failure of anti-biotics to take effect are important factors (Hellner 1966) Bouts of slight fever, elevated erythrocyte sedimentation rate leucocytosis and serological findings are not conclusive (Hladik et al 1967) Even in biopsy it is difficult to distinguish between Ewing s sarcoma and osteo-myelitis (Banshali et al 1963 Hellner 1966) Benign bone lesions are frequently misdiagnosed as malignant especially in children A misdiagnosis, either in children or adults mav have tragic consequences (Copeland 1964)

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The relationship between the curative possibilities of radiation treatment and the size of the tumour is clear If the area of the malignancy is small it responds better to radiation and it is thus important to remove the tumour as far as possible by means of palliative surgery before giving radiation treatment Sub clinical micro metastases can be destroyed with a dose of 5 000—6 000 rad but a primary tumour cannot be cured with such a dose Radiation treatment is thus indicated for metastases in the lungs or regional lymph nodes Two successive doses of 200 rad are indicated for preoperative radiation before biopsy (von Ronnen et al 1974)

Palliative radiation treatment is important for slowing down temporarily the growth of a tumour in cases where surgical measures are impossible on account of the anatomical location or because of vital function Such tumours are often situated in the base of the skull the spine or the pelvis (Beck et al 1976)

Solitary myeloma and extra medullary plasma cytoma can be cured by radiation

The clinically effective radiation dose for osteo sarcoma is between 4 000 and 9 000 rad given 1 000 rad per week (Woodard et al 1947)

According to present ideas radiation treatment alone without up-to-date cytostat treatment is not indicated (Beck et al 1976)

2 13 8 Treatment with cytostatic agents

Treatment with cytostatic agents has developed considerably in recent years Earlier it was mostly used palliatively and as an adjunct to radiation treatment Nowadays cytostat treatment is used actively and as an integral part of overall treatment (Sack 1976) There have been big changes in the doses of drugs given The intra arterial administration of cytostat agents is at the experimental stage (Oka 1970) Different drug combinations and mammoth doses have given encouraging results (Lochshin et al 1963 Price et al 1975 Rosen 1975 Akahoshi et al 1977 Copeland 1977 Huvos et al 1977 Jaffe 1977 Kotz et al 1977 Grohn et al 1978 Nikkanen 1978) Cytostat treatment carries with it the risk of a carcinogenic effect Renner (1971) found that a primary benign tumour became malignant owing to the effect of cytostat treatment The sensiti

Table 5 Sensitivity of primary malignant bone tumours to cytostatic agents (Sach 1976)

Degree of sensitivity	Effect *	Tumour
I	= 10	Chondro-sarcoma
II	= 30	Ewing s sarcoma
III	= 40	Osteo-sarcoma lipo sarcoma malignant giant cell tumour neuro-sarcoma
IV	= 50	Bone marrow tumours fibro-sarcoma angio-sarcomas Undifferetiated sarcomas

Table 4 Sensitivity to radiation of primary malignant bone tumours (Sherman 1956 Cade 1955 *Millburn et al 1968 van der Heul et al 1967 Wang 1968* Phillips et al 1969 Dahlin 1964 1972)

	Sensitive to radiation	Moderately sensitive to radiation	Radiation resistant
Bone forming tumours			
Osteo-sarcoma			+
Parosteal osteo-sarcoma			+
Cartilage forming tumours			
Primary chondro sarcoma			+
Secondary chondro sarcoma			+
Parosteal chondro-sarcoma			+
Mesenchymal chondro sarcoma			+
Giant cell tumours			
Malignant giant cell tumour			+
Bone marrow tumours			
Ewing s sarcoma	+		
Reticulum-cell sarcoma	+		
Lympho-sarcoma	+		
Myeloma	+		
Vascular tumours			
Angio sarcoma		+	
Haemangio-endothelioma-sarcom		+	
Haemangio pericytoma sarcoma		+	
Other connective-tissue tumours			
Fibro sarcoma			+
Lipo sarcoma		+	
Malignant mesencymoma		+	
Primary malignant fibrous histio cytoma			+
Undifferentiated sarcoma		+	
Radiation sarcoma			+
Other tumours			
Chordoma		+	
Adamantinoma of long bones			+
Neuro sarcoma		+	

resections Radiation treatment de-vitalizes the surrounding tissue and reduces the likelihood of success of bone transplant (Koskinen et al *1968 McCormack 1978)* The schema for treatment proposed by Ferguson (1940) in which preoperative necrotizing *radiation and* late amputation are used *still has its supporters* (Cederlof et al 1961 Aakhus et al 1963 Lissner 1969 Heilman 1971) There is still today uncertainty *about the value of preopera-*tive radiation treatment *Preoperative ra*diation in osteo-sarcoma is without value (von Ronnen et al 1974 *Nordman 1979)*

Table 6 Five year and ten year survival rates for osteo-sarcoma in different reports

Investigator(s)	Patients No	5 year No	survival %	10 year No	survival %
MacDonald et al (1943)	118	14	11 8		
Poppe (1949)	20	2	10 0	1	5 0
Cade (1955)	133	16	12 0		
Coventry et al (195?)	430	83	19.3	45	15.3
Cederlof et al (1961)	27	3	11 1		
Lindbom et al (1961)	96	18	18 8		
Platt (196?)	1?1	30	24 8	15	12 4
Aakhus et al (1963)	71	6	8 5		
Price (1966)	130	?0	15 4		
Copeland et a (1967)	121	19	15 7		
Dahlin (19?2)	408	83	20.3	10	2.5
Price et al (19 ?)	125				
	1 800	294	16.3	71	7.3

different types of tumour As far as prognosis is concerned no difference between the sexes has been discovered (Dahlin et al 1969) Prognosis has improved as treatment has developed (Lochshin et al 1963 Dahlin et al 1969)

2 14 2 Bone forming tumours

2 14 2 1 Osteo sarcoma

The 5 year survival rate for osteo-sarcoma varies between 10 % and 30 % in different studies The results of surgery are better than those of radiation

There is no certain evidence that preoperative radiation treatment improves the prognosis for sarcoma (Beck et al 1976)

The location of the tumour is important for prognosis (Holsti et al. 1973) The prognosis for tumours in the elbow and knee joints is better if they are located distally than if they are proximally situated (Coventry et al 1957 Dahlin et al 1967) There is a good prognosis for tumours of the

Table 7 Five year survival rate for osteo-sarcoma when treated surgically with radiation only and with pre operative radiation according to Lochshin et al 1963

Investigator(s)	Surgical treatment		Radiation only		Pre-operative rad.	
	No of patients	5 y s %	No of patients	5 y s %	No of patients	5-y s %
Farrel	17	5 9	9	0	16	43.8
Francis	25	12 0			33	26 2
Hayles	101	20 8	15	6 7		
McKenna	101	21 8	22	0 0	93	12 9
Phelan	35	1? 1	12	8.?	5	0 0
	279	19 0	58	3 4	147	17 0

vity of primary malignant bone tumours to cytostat treatment is different from their sensitivity to radiation

Cytostatic agents have long been the basic treatment for myeloma With cytostats it has often been found that metastases either disappear or become smaller (Sack 1976) There is no information available as yet about the effect on prognosis in a long-term follow-up Before the introduction of massive cytostat treatment 80 % of osteo-sarcoma and Ewing s sarcoma patients died within two years after the making of the diagnosis With the present treatment 80 % are still alive after two years (Ivins et al 1976 Jenkin et al 1976, Dissing et al 1977 Jaffe 1977)

In treating recurrence of tumour and metastases the most important method is combined surgical and cytostat treatment (Oldhoff 1970)

2 13 9 Immunological treatment

The immunological treatment of primary malignant bone tumours is at the experimental stage Encouraging results have been achieved in individual cases (Koskinen 1976, Tallberg 1976 Salenius 1977) In connection with immunological resistance, the spontaneous disappearance of tumours has been observed (Copeland 1975)

2 13 10 Interferon

For the treatment of osteo-sarcoma and multiple myeloma interferon is at the experimental stage and preliminary results are encouraging (Cantell 1978 Idenstrom et al Mellstedt et al 1979)

2 13 11 Treatment of pathological fractures

Pathological fractures are common among bone tumour patients Surgical treatment of fractures is very important for relieving pain One useful method is intra-medullary nailing of long bones combined with radiation treatment (Marcove et al 1967 Phelan 1968, Cech 1970, Koskinen et al 1973) Prophylactic osteosynthesis is necessary, for example, if there is a large myeloma nodule in the diaphysis of the femur There is no evidence that nailing leads to the spread of a tumour (Phelan 1968, Harrington 1977)

Marcove s report (1967) on patients who underwent surgery after pathological fracture showed that 40 % lived for over six months postoperatively and 34 % for over a year If the patients had multiple fractures 39 % lived 1—6 months and 26 % more than one year Complications after surgery were common

2 13 12 General treatment

Care of patients suffering from primary malignant bone tumours is very important in order to improve their general condition and their immunity Many patients are seriously disabled by the disease and its treatment their resistance and mental stability being shaken The patient must be treated as a totality

2 14 PROGNOSIS

2 14 1 General

The prognosis for primary malignant bone tumours is considered to be serious (Platt 1962) though it is very different for

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Phelan	35	17 1	1?	8 3	5	0 0
	279	19 0	58	3 4	147	17 0

Table 8 Effect of location of osteo-sarcoma on 5-year and 10-year survival rates

Location and investigator(s)	No of patients	5-y s %	No of patients	10 y s %
Antebrachium (Dahlin et al 1967)		35 5		
Tibia (Dahlin 1972)		36 6		
Tibia (Coventry et al 1957)		*34 6*		
Femur (Dahlin 1972)		17 6		
Humerus and femur (distal) *(Dahlin 1972)*	71	25 4		
Knee & elbow joints (distal)	38	35 8		
Scapula-clavicula		13 0		
Mandibula (Kragh et al 1958)	19	17 6		
Mandibula (Garrington et al 1967)	22	41 0	13	38 0

lower jaw (Kragh et al 1958, Garrington et al 1967, Finkelstein 1967)

The prognosis for osteogenic sarcoma in soft tissue is the same as for tumours originating in bone (Fine et al 1956)

The prognosis for osteo-sarcoma is better for females than for males (Lindbom et al 1961 Platt 1962) This may be because of the location of tumours Tumours in females are more often situated in the limbs (Foster et al 1964)

It is generally thought that the age at which *tumours develop has no effect* on prognosis (Dahlin 1967) In many studies however the prognosis has been better for patients between 20 and 40 years old (Coley et al 1940 Cederlof et al 1961 Price 1966) The prognosis for osteo-sarcoma is better when symptoms are of *long duration than when there is a tumour* that has produced symptoms only for a short time (Cederlof et al 1961)

Prognosis is poor for osteo-sarcoma that results from Paget s disease (Lockshin et al *1963 Ross 1964* McKenna et al *1964* Price et al 1969) For osteo-sarcomas that developed from Paget s disease Platt (1962) reported a 5-year survival rate of 2 % and Price (1969) a 5-year survival rate of 5 %

On the other hand, the *prognosis* for tumours of the lower jaw is rather good (Finkelstein 1967)

The prognosis for osteo-sarcoma is better if the tumour can be removed radically by surgical means as soon as the diagnosis is certain In osteo-sarcoma conservative ablative treatment is *often sufficient* (Sneppen et al 1978) Osteo sarcoma also produces *metastases* very rapidly in the lungs, liver and bones it also recurs locally Ten per cent of osteo sarcoma patients have metastases in the regional lymph nodes when they come for treatment *(Caceres et al 1969) If the patient* has metastases in the *regional* lymph nodes the prognosis *is* worse than otherwise (Baumann 1970 Rao et al 1977) In cases of osteo-sarcoma it has been found that radiation *treatment either makes them* disappear or at least reduces them in size (Francis et al 1962) Removal of the regional lymph nodes worsens the prognosis in cases of osteo-sarcoma (Rao et al *1977)* In *osteo-sarcoma* patients who *survived* for more than ten *years* there was no clear explanation as to why these had survived and not the others (O Hara et al 1968)

2 14 2 2 Parosteal osteo sarcoma

It is typical of parosteal osteo-sarcoma that the prognosis is better than for osteo-sarcoma in general and also that late metastases may develop as long as sixteen years after primary treatment (Shaghetti et al 1962 van der Heul et al 1967 Wolfel et al 1969) After local excision the tumour always recurs (Dwinnel et al 1954 Stevens et al 1957)

The recommended treatment for parosteal osteo sarcoma is resection combined with bone transplant or amputation (Shaghetti et al 1962 van der Heul et al 1967) A small tumour which has histopathologically low grade malignancy is treated by en bloc resection large tumours by amputation Pre-operative radiation is not recommended (Wolfel et al 1969) The plan for treatment must be made on the basis of clinical examination and X ray examination (Wolfel et al 1969)

The five-year survival rate for parosteal osteo-sarcoma is more than 50 % (Copeland 1967) If adequate treatment is given early enough the majority of patients recover (Dahlin 1972) The five-year survival rate for parosteal osteo-sarcoma does not correspond exactly to the progress of the disease because late metastases are common There are no figures available for long term follow ups of ten years or more For individual cases of osteo sarcoma the prognosis is better than for other primary malignant bone tumours

Recurrence of the tumour is common in parosteal osteo sarcoma (van der Heul et al 1967) and the tumour forms metastases in the same organs as osteo sarcoma in general

2 14.3 Cartilage forming tumours

2 14.3 1 Chondro sarcoma

The best treatment for all chondrosarcomas is radical surgery (Lindbom et

Table 9 Principles for treating parosteal osteo-sarcoma (van der Heul et al 1967)

— local excision leads to recurrence
— after resection recurrence is less common
— amputation as primary treatment does not always prevent metastases from forming
— radiation treatment has no effect
— excision of new tumour does not prevent further recurrence on the contrary a further tumour will develop even more rapidly

Table 10 Five year survival rate for parosteal osteo-sarcoma when treated surgically

Investigator(s)	Patients No	5 year survival No	%
Dwinnel et al (1954)	15	10	66 7
Copeland et al (1964)	18	11	61 1
van der Heul et al (1967)	16	11	68 8
Dahlin (1972)	25	19	76 0
	74	51	68 9

al 1961, Foster et al 1964) Chondro-sarcoma is localized in 50 % of patients when they present themselves for treatment (Foster et al 1964) A biopsy should be carried out before any treatment is given (Dahlin 1972) The results of local excision in chondro-sarcoma seem to be good but this procedure fails to prevent metastases from forming (Lindbom et al 1961, Dahlin 1972) If chondro-sarcoma is treated radically, either the tumour recurs or metastases follow quickly and the prognosis is poor (Copeland 1967) Radiation treatment has no effect on chondro-sarcoma but in tumours located in the pelvis and in the spine it has a clear palliative effect and suppresses patients symptoms for a long time If chondro sarcoma is treated in the same way as osteo-sarcoma the results age good (Marcove 1977) As far as prognosis is concerned there is no difference between the sexes

The histo-pathological distribution of chondro-sarcoma is important for prognosis The best prognosis is that for juxta-cortical chondro-sarcoma and the worst is for menenchymal, which forms early metastases (Dahlin 1972, Wu et al 1977)

The prognosis for chondro-sarcoma is better when it is peripheral than when it is centrally situated It is seldom possible to perform radical treatment when the tumour is in the spinal or pelvic region and therefore the results of treatment are usually poor (Dahlin et al 1956)

The 5-year survival rates for chondro sarcoma patients undergoing radical surgery are between 30 % and 70 % The results of palliative surgery are exceptionally unfavourable In Lindbom s series (1961) metastases developed in 75 % of the patients Phelan (1964) reported that metastases developed in all patients treated with local surgery There are few reports dealing with chondro-sarcoma patients who have received radiation treatment only and such reports as there are show extremely poor results Spontaneous recovery has occasionally been reported (McLaughlin et al 1979)

Table 11 Five-year survival rate for chondro sarcoma according to method of treatment

Investigator(s) and treatment	Patients No	5 year survival No	%
Copeland et al (1949) radical surgery	86	38	44 2
Lindbom et al (1961) radical surgery	[illegible]3	14	60 9
Lindbom et al (1961) radiation	16	1	6 3
Henderson et al (1963) radical surgery	92	68	73 9
Henderson et al (1963) various methods	132	49	37 1
Copeland (1967) radical resection or radical amputation	118	45	38 1
	467	215	46 0

2.1.4.4 Giant cell tumours

2.1.4.4.1 *Malignant giant cell tumour*

The treatment for giant-cell tumours is the same as for osteo-sarcoma (Jaffe 1953 Hutter et al 1962) The present treatment radical resection and bone transplant (autotransplant or allotransplant) has given encouraging results in individual cases (Jaffe 1955 Koskinen 1978) Palliative resection or evacuation leads to recurrence of the tumour in 85 % of cases (Goldenberg 1970 Koskinen 1978) Radiation treatment usually has no effect on giant-cell tumours but it has been found to give some relief in the case of tumours situated in the pelvic region (Cade 1955 Murphy et al 1956 Dahlin 1972) Herenden (1924) described the paradoxical responce in which radiation treatment activates giant-cell tumours in a more malignant direction

The prognosis for malignant giant-cell tumours is good if primary treatment is radical and there is no recurrence of tumour nor do metastases develop (Koskinen et al 1978) Prognosis is usually poor if the tumour recurs (Dahlin 1972 Koskinen 1978) Radiation treatment has no effect on a recurrent tumour (Williams et al 1964)

2.1.4.5 Bone marrow tumours

2.1.4.5.1 *Ewing s sarcoma*

Ewing s sarcoma is a tumour that is sensitive to radiation and produces early metastases (Copeland 1967) For this reason the tumour has more frequently been treated with radiation than by surgery (Banshali et al. 1963 Jenkin et al 1975) Patients suffering from Ewing s sarcoma are young and thus treatment must meet special demands No cases of spontaneous recovery have been recorded (Bethge 1953)

Results of treatment vary Some have considered the disease to be hopeless and as recently as 1964 Dahlin reported that only one per cent of Ewing s sarcoma patients recovered as a result of treatment Prognosis is considered to be slightly better for women than men because tumours are usually nearer the periphery in women (Foster et al 1964)

The results of radiation treatment and radical surgery are similar The 5-year survival rate is approximately 10 % Results of treatment have improved somewhat in the last few years because patients have come sooner for treatment Diagnostic improvement has also had a positive effect (Foster et al 1964)

25 % of patients suffering from Ewing s sarcoma are found to have metastases when they present themselves for treatment (Banshali et al. 1963) Because of the early formation of metastases pre-operative radiation combined with amputation after 4—6 months is still practised as a method of treatment The significance of surgical treatment for Ewing s sarcoma has not lessened (Banshali et al 1963) Palliative radiation treatment is useful in cases where the tumour is far advanced (Dahlin et al 1961) 75 % of those suffering from Ewing s sarcoma have either died or are in the terminal phase of the disease within two years of its being diagnosed (Copeland 1967 Baird et al 1963)

Surgical treatment of distant metastases has in certain cases proved successful (Macintosh et al 1975) Encouraging results have been achieved in recent years when micro-metastases have been treated

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Table 13 Five-year and ten year survival rates for reticulum-cell sarcoma

Investigator(s) and treatment	Patients No	5 year survival No	%	10-year survival No	%
Coley et al (1950) radiation	21	10	47 6	6	28 6
Francis et al (1955) radiation	31	15	48 4		
Ivins (1963) treatment not specified	46	16	34 8		
Wang et al. (1968) radiation or surgery	10	5	50 0		
Shoji et al (1971) treatment not specified	46	19	41 3		
Miller et al (1971) radiation & surgery	35	15	42 1		
Coley toxin	47	30	63 8		
	236	110	46 6	6	28 6

sarcomas (Craver et al 1934) Treatment and prognosis are about the same as for reticulum-cell sarcoma (Mincey et al 1974)

2 14 5 4 Myeloma

The basic treatment for myeloma is cytostats radiation and surgery combined with good general treatment (Biro 1971 Palva 1979) Surgery alone should be the treatment for solitary nodules in the limbs and extra medullary plasma cytoma

50 % of myeloma patients react well to cytostat treatment (Copeland 1967) The most effective cytostats are cyclophosphamide and melphalan Nitrogen mustard which was used earlier had a good primary effect but its duration was limited Urethane (ethyl carbamate) has a beneficial effect on 20 % of patients and its power to prevent the growth of osteolytic tumours has been emphasized (Copeland 1967) Urethane combined with cytostats is of no avail (Copeland 1967) Cortisone reinforces the effect of urethane

Cortisone has a beneficial effect especially on older myeloma patients (Biro 1971) On the other hand cortisone adds to the complications of myeloma provoking especially renal insufficiency and amyloidosis (Biro 1971) 80 % of myeloma patients have neuropathy (Davis et al 1972 Dahlin 1972) Cortisone is most valuable for myeloma patients with the hyper-calcemic syndrome in which psychopathy wasting of the muscles polyuria and constipation occur (Copeland 1967)

Anabolic hormones improve the patient's general condition Gammaglobulin administered 3—4 times a month prevents infections and helps the patient to recover from them (Biro 1971)

Radio-active phosphorus and fluoride are used sometimes in treating myeloma It has been discovered by means of X-rays that when treating myeloma with radioactive drugs trabeculation is strengthened and the damage is repaired (Cook et al 1968)

The proportion of solitary myelomas is approximately 10 % (Dahlin 1964) The

Table 12 Five-year and ten year survival rates for Ewings sarcoma

Investigator(s) and treatment	Patients No	5-year survival No	%	10 year survival No	%
McCormack et al (1952)					
whole material	63	8	12 7	6	9 5
radiation treatment	37	4	10 8	3	8 1
surgery	26	4	15 4	3	11 5
Wang et al (1953)	50	7	14 0		
Platt (1962)	30	8	26 7	5	16 7
Baird et al (1963)	107	3	2 8		
Banshali et al (1963)	14	2	14 3	0	0 0
Phelan et al (1964)	940	102	10 9		
Falk et al (1967)	54	13	24 1		
Phillips et al (1967)	33	3	9 1		
Dahlin (1972)	210	32	15 2		
	1564	186	11 9	17	10 0

with massive cytostat combinations There are no follow-up studies as yet

2 14 5 2 Reticulum cell sarcoma

Reticulum-cell sarcoma is sensitive to radiation and it forms metastases rather late For this reason many investigators recommend radiation as primary treatment for this type of tumour (Ulrich et al 1958 Wang et al 1968 Jack et al 1975) If radiation has no effect locally surgical treatment is indicated (Wang et al 1968 Shoji et al 1971) A further drawback of radiation treatment is that it inactivates the resistance of the reticulum-endoteliate system and thus weakens the patient s immunity to the tumour (Miller et al 1971)

The results of surgery and radiation in the treatment of reticulum-cell sarcoma are similar some hospitals favouring the one and some the other Surgeons are in favour of radical surgery because the necrosis that follows radiation treatment causes difficulties (Boyes 1974) In any case radiation seldom succeeds in preventing the growth of a primary tumour (Dahlin 1972) High amputation has proved a successful method for treating tumours in the distal part of the femur (Boyes 1974) Post-operative radiation treatment is recommended for reticulum-cell sarcoma (Francis et al 1955)

Primary treatment of the lymph nodes is important in dealing with reticulum cell sarcoma because the tumour easily spreads along the lymphatic ducts (Tikka et al 1969 Shoji et al 1971 Tallroth 1976) Surgery and radiation are considered to be equally effective for this (Dahlin 1972) In cases where reticulum cell sarcoma is far advanced cytostat treatment is useful (Shoji et al 1971 Dahlin 1972)

The five-year survival rate for reticulum-cell sarcoma is approximately 50 % If the tumour is situated in the pelvic region the prognosis is worse (Shoji et al 1971)

2 11 5 3 Lympho sarcoma

Primary lympho-sarcomas of the bone account for about 10 % of all lympho

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sarcomas (Craver et al 1934) Treatment and prognosis are about the same as for reticulum cell sarcoma (Mincey et al 1974)

2 14 5 4 Myeloma

The basic treatment for myeloma is cytostats radiation and surgery combined with good general treatment (Biro 1971 Palva 1979) Surgery alone should be the treatment for solitary nodules in the limbs and extra medullary plasma cytoma

50 % of myeloma patients react well to cytostat treatment (Copeland 1967) The most effective cytostats are cyclophos phamide and melphalan Nitrogen mu tard which was used earlier had a good pri mary effect but its duration was limited Urethane (ethyl carbamate) has a bene ficial effect on 20 % of patients and its power to prevent the growth of osteolytic tumours has been emphasized (Copeland 1967) Urethane combined with cytostats is of no avail (Copeland 1967) Cortisone reinforces the effect of urethane

Cortisone has a beneficial effect especi ally on older myeloma patients (Biro 1971) On the other hand cortisone adds to the complications of myeloma provoking especially renal insufficiency and amy loidosis (Biro 1971) 80 % of myeloma patients have neuropathy (Davis et al 1972 Dahlin 1972) Cortisone is most valuable for myeloma patients with the hyper calcemic syndrome in which psy chopathy wasting of the muscles polyuria and constipation occur (Copeland 1967)

Anabolic hormones improve the patient s general condition Gammaglobulin admi nistered 3—4 times a month prevents in fections and helps the patient to recover from them (Biro 1971)

Radio-active phosphorus and fluoride are used sometimes in treating myeloma It has been discovered by means of X-rays that when treating myeloma with radio-active drugs trabeculation is strengthened and the damage is repaired (Cook et al 1968)

The proportion of solitary myelomas is approximately 10 % (Dahlin 1964) The

treatment for solitary myeloma is preoperative radiation and radical resection (Benedict 1970, Dahlin 1972) Prognosis for solitary myeloma is good, provided there is no dissemination in the bone marrow (Cohen et al 1964) The treatment for extra-medullary plasma-cytoma is a combination of radiation and surgery (Gosepath et al 1969 Wiltshaw 1976)

In cases of myeloma palliative surgery and radiation are very significant in the treatment of paralysis caused by pathological fractures of the spine (Martin et al 1970) Radiation should be preceded by a decompressing operation (Dahlin 1972) When a limb is fractured, intra-medullary osteo-syntheses are best used in combination with post-operative radiation treatment Prophylactic intra-medullary nailing is sometimes necessary to prevent a fracture (Koskinen 1976)

Prognosis for myeloma has been considered to be hopeless Copeland (1967) reported that in his material not a single patient had recovered from myeloma and only a few patients lived for more than five years A similar picture is given by Baldwin, et al (1967) In Dahlin s material (1972) the majority of the patients died less than two years after the appearance of the first symptoms, the average period of survival being 13 months Five-year survival rates are usually under 10 % The prognosis is generally better if the disease is local It has been observed that solitary myeloma spreads after several years (Richards 1972) The prognosis for myeloma correlates poorly with radiological changes at the time of diagnosis (Gompels et al 1972)

It has been reported that myeloma develops in various different ways In young people the disease sometimes begins gradually, the M-component is small bone changes are peripheral marrow smear normal — and the tumour develops slowly (Waldenstrom 1970)

Prognosis for solitary myeloma in the spine is rather good In a study comprising 55 patients (Cohen et al 1964) 33 % were still alive five years after the moment of diagnosis There have been individual cases where patients with solitary myeloma, treated with radiation, have lived as much as 30 years (Pankovich et al 1972)

The immunological distribution of myeloma is important for the prognosis In Baldwin s material (1967) the average period of survival for IgG myeloma patients was 25 3 months and for IgA myeloma patients 26 6 months In Glenchur s material (1958) prognosis was worst if electrophoresis was normal It has been reported that radiation gives best results in the treatment of IgG myeloma (Maryana 1970)

The prognosis for extra-medullary plasma-cytoma is not known exactly It is generally considered to be much better than for multiple myeloma (Gosepath et al 1969 Poole et al 1968) The location of the tumour and the degree of spreading affect the prognosis (Boyd et al 1969) After treatment late recurrence of tumours has been observed as much as 20—36 years subsequently (Gosepath et al 1969)

The immediate cause of death in myeloma patients is usually infection renal insufficiency cardiac insufficiency paralysis or haemorrhage (Martinez-Maldonado et al 1971) In myeloma patients hypertony is not associated with nephropathy (Biro 1971) Especially in the case of geriatric patients the use of contrast infusions

in X ray studies of the kidneys of myeloma patients is contraindicated on account of irreversible changes in the kidneys (Biro 1971) In Glenchur's study of 51 terminal myeloma patients the immedia e cause of death in 17 cases was pneumonia Other infections were present in a furthe 29 patients

2 14 6 Vascular tumours

2 14 6 1 Angio sarcoma

Individual cases of angio-sarcoma have been treated in the same way as osteo-sarcoma (Dahlin 1972) Angio-sarcoma often causes extensive os eolytic damage and surg cal treatment is often necessary on account of pathological fracture Prognosis is similar to that for osteo sarcoma (Dahlin 1964)

2 14 6 2 Haemangio endothelioma sarcoma

Treatment and prognosis for haemangio-endothelioma sarcoma are the same as for osteo sarcoma

2 14 6 3 Haemangio pericytoma sarcoma

Treatment and prognosis for haemangio-pericytoma-sarcoma are the same as for osteo sarcoma

2 14 7 Connective tissue tumours

2 14 7 1 Fibro sarcoma

Fibro sarcoma is a tumour that is resistant to radiation and treatment is the same as for osteo sarcoma (Dahlin 1972) There are two types of fibro sarcoma secondary and medullary It is difficult to distinguish between the fibro-plastic type of osteo-sarcoma and fibrotic dysplasia (McLeod et al 1957) About 20 % of cases are secondary fibro-sarcoma the etiology being fibrous dysplasia Paget s disease or giant cell tumour (Eyre-Brook et al. 1969) The prognoses for medullary and secondary fibro-sarcomas are similar to that for primary fibro-sarcoma (Gilmer et al 1958 Dahlin 1972) Some investigators consider the prognosis for fibro-sarcoma to be just as poor as that for osteo-sarcoma (Coventry et al 1957)

2 14 7.2 Lipo sarcoma

Lipo sarcoma is a malignant tumour which produces early metastases in the lungs and liver Treatment and prognosis are the same as for osteo-sarcoma (Dawson 1955 Catto et al 1963 Goldman 1964)

2 14 7 3 Malignant mesenchymoma

Malignant mesenchymoma is very rare and the tumour has features in common

Table 14 Five year and ten year survival rates for fibro-sarcoma

Investigator(s)	Patients No	5 year survival No	%	10-year survival No	%
Gilmer et al (1958)	227	59	26 0		
Eyre Brook et al (1969)	50	14	28 0	6	12 0
Dahlin et al (1969)	92	25	27.2	20	21 6
Pritchard et al (1977)	158	45	28 7	34	21 8
	527	143	27 1	60	20 0

with osteo-sarcoma and lipo-sarcoma (WHO Schajowicz et al 1972)

2 14 7 4 Primary malignant fibrous histio cytoma

Primary malignant fibrous histiocytoma is the latest malignant bone tumour to be discovered Typical of it are extensive osteolytic damage and pathological fracture (Spanier 1977) The tumour forms early metastases like osteo-sarcoma (Spanier et al 1975)

There is as yet no clear idea about how to treat primary malignant fibrous histiocytoma Radical surgery combined with radiation treatment has been used (Spanier et al 1975 Feldmann et al 1977) This has been justified on the basis of a possible connection between this type of tumour and lympho-sarcoma or reticulum-cell sarcoma (Spanier et al 1975) Prognosis is poor In Spanier s material, the average period of survival after treatment was 21 months Slootweg et al (1977) and Webber et al (1977) report similar results Prognosis is better for a malignant fibrous histiocytoma located in soft tissue (Rantakokko 1978)

2 14 7 5 Undifferentiated sarcoma

Undifferentiated sarcoma is a little known tumour with features of osteo-sarcoma reticulum-cell sarcoma fibro sarcoma and metastatic carcinoma (Schajowicz 1972)

2 14 7 6 Radiation sarcoma

Radiation sarcoma is a very malignant tumour (Schwartz et al 1958) The prognosis for a tumour that has developed in the place of a benign bone lesion is generally better than for osteo-sarcoma (Arlen et al 1971) Treatment and prognosis for radiation sarcoma are the same as for osteo-sarcoma (Steiner 1965, Mindell et al 1977)

2 14 8 Other tumours

2 14 8 1 Chordoma

Chordoma is a rare tumour It accounts for 1 5 % of all malignant bone tumours (Paavolainen et al 1976) Chordoma originates from the notochord the remains of the notochord or from the nuclei pulposi 10 % of chordomas produce metastases by the haematogenous route Deposits may develop in unusual locations including the skin Recurrence may take place after many years (Dahlin 1972)

There is not complete agreement about how to treat chordoma Because the tumour grows slowly partial resection gives years of remission and the patient is symptom-free Some chordomas are sensitive to radiation Radical surgery is seldom possible for spheno-occipital chordoma and partial resection and post-operative radiation are generally indicated (Greenwald et al 1957 Dahlin et al 1952 Paavolainen et al 1976) Surgical treatment is necessary for sacrococcygeal chordoma The prognosis for chordoma is directly related to how the tumour is treated surgically Radical excision of a spheno-occipital tumour is seldom possible Tumours in this area easily cause lethal pressure in the region of the medulla oblongata It is quite often possible to remove a sacrococcygeal chordoma by radical surgery and then the prognosis is good (Kamrin et al 1964 Rissanen et al 1967 Paavolainen et al 1976)

2 14 8.2 Adamantinoma of long bones

Adamantinoma of long bones is a rare tumour the treatment for which is like that for osteo-sarcoma (Dockerty et al. 1942) Metastases are common after resection (Dahlin 1972)

2 14 8.3 Neuro sarcoma

Treatment for neuro-sarcoma is the same as that for osteo sarcoma Prognosis is only known from a few individual cases and is usually very unfavourable (Güthert 1972)

with osteo-sarcoma and lipo-sarcoma (WHO, Schajowicz et al 1972)

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4 MATERIAL AND METHODS

The material for this study has been supplied by the Finnish Cancer Registry and consists of all primary malignant bone tumours reported between 1962 and 1968 During that period 985 cases were reported The incidence was 3 16 cases per year for 100 000 inhabitants During the same time an average of 10 958 tumours of all types were reported annually (Teppo et al 1975) Primary malignant bone tumours accounted for 1 25 % of all malignant tumours Included in the clinical follow up study were patients whose diagnoses had been confirmed by histo pathological tests accompanied by a statement from a specialist Giant cell tumours were considered malignant if they were found to be malignant either clinically or histo pathologically or both Diagnosis of myeloma was considered certain if it was based on the results of histo-pathological examination or if it was supported by clinical examination X ray examination and laboratory findings Tumours originating in the teeth are not included in this study

The series finally comprised 869 patients whose case histories X rays and histo pathological samples were collected for further study

There were 86 patients (8 7 % of the original 985 cases) for whom no case history could be found and 20 (2 0 %) for whom the case histories were defective These patients were excluded from the study

Histo pathological samples from 273 (86 4 %) sarcoma patients and 45 (8 1 %) myeloma patients were available for further study In 10 cases it was certified in the further study that a primary malignant bone tumour was not involved In 36 cases (13 2 %) the diagnosis was modified in the light of histo-pathological clinical and X ray examinations

Further study of the histo-pathological samples was made by Docent Tapani Sorvari at the university of Kuopio and in problematic cases assistance was also given by Professors Osmo Jarvi Erkki Saxen L V Ackerman and H A Sissons The author has familiarized himself with the histological study of bone tumours under the guidance of Dr Sorvari

Re analysis of the X-rays was carried out by Professor Pekka Virtama and Dr Kalevi Katevuo using the computer-assisted diagnosis developed by Lodwick

Information about survival was checked personally in hospitals church registers and in documents provided by the Finnish Central Office for Statistics The follow-up period varied from six years to eleven years eleven months (average 6 1/ years) The follow up ended on 31 12 1974

Surgical intervention was considered to be radical if amputation or resection allowed a distance of 5 cm from the di-

3 PURPOSE OF THE STUDY

The purpose of the study is to clarify the clinical picture methods of treatment and follow-up results of primary malignant bone tumour and to attempt an answer to the following questions

- How common are primary malignant bone tumours in Finland?
- What symptoms do bone tumour patients have and what are the findings?
- Where are the tumours located?
- What is the treatment to be given?
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5 RESULTS

5.1 INCIDENCE AGE AND SEX DISTRIBUTION

The clinical study comprised 869 patients suffering from primary malignant bone tumour Incidence was 2.7 new cases per 10^5 inhabitants annually The average age of the patients was 54.7 years the youngest being two years old and the oldest 93. 82.5 % of the patients were over 40 and there were 442 men (50.9 %) and 427 women (49.1 %)

5.2 HISTOLOGICAL DISTRIBUTION

There were 21 different histological types of tumour It was possible by means of electrophoresis to classify 494 (89.3 %) of the 553 myeloma patients into immunological sub-groups (Table 15) Of the myeloma patients 262 (47.4 %) were male and 291 (52.6 %) were female Of the remaining patients i e those with sarcoma 180 (57.0 %) were male and 136 (43.0 %) were female In the case of 18 sarcoma patients the sample was too small or too badly preserved for it to be possible to classify it in further study but it was nevertheless possible to confirm that sarcoma was involved Histological age distribution is shown in Figs 21—35

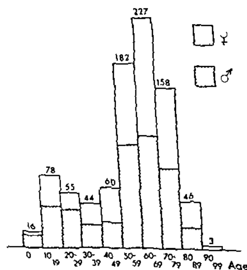


Figure 1 Age distribution of 869 patients with primary malignant bone tumour

5.3 SYMPTOMS AND DIAGNOSIS

5.3.1 Pain

Pain is the most common symptom of malignant bone tumours 280 (88.6 %) of the sarcoma patients and 511 (92.4 %) of the myeloma patients experienced pain at the place of the tumour In 566 cases (71.6 %) it was considered to be referred pain or neurological pain

5.3.2 Size of tumours and resistance to palpation

In sarcoma patients tumours were on the average 6.0 cm in diameter

There was a palpable tumour in 260 patients (29.9 %) 209 (66.1 %) of whom were

seased tissue It was considered to be local if the distance was less than 5 cm Biopsy was not considered to be part of treatment

The histological classification of tumours according to their degree of malignancy was made on the basis of the recommendations published by the World Health Organization in 1972, together with a complementary classification of additional tumours drawn up by Docent Tapani Sorvari

Crude survival of patients was calculated by means of the so-called actuary technique (Cutler et al 1958) This procedure makes it possible to include all the information available, regardless of the length of the follow-up time In order to eliminate the part played by the normal mortality rate, the figure obtained for crude survival was compared with the normal mortality rate for a population of the same age The latter was calculated from tables supplied by the Central Office for Statistics The relationship between the two figures is called age-corrected or relative survival (Ederer et al 1961)

The normal laboratory values were based on Laboratoriotutkimusten vertailuarvoja by Leskinen et al 1972

Statistical significance was calculated by the Mantel-Haenszel method

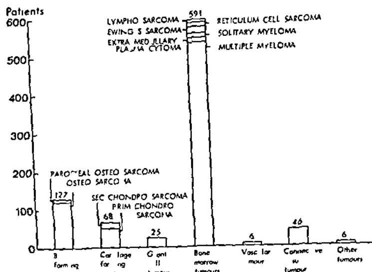


Figure ? Histological distribution of 869 primary malignant bone tumours

sarcoma patients and 51 (9 2 %) myeloma patients

5 3 3 Pathological fracture

There was pathological fracture in 310 patients (35 7 %) Of these 58 (18 4 %) were sarcoma patients and 252 (79 5 %) were myeloma patients

5.3 4 Deterioration of general health

Deterioration of general health was a symptom in 491 patients (56 4 %) of whom 41 (13 0 %) were sarcoma patients and 450 (81 4 %) were myeloma patients 28 (8 9 %) of the sarcoma patients and 380 (43 7 %) of the myeloma patients reported that they had lost weight

5 3 5 Trauma in anamnesis

Only 7 patients (0 8 %) reported certain trauma in the region of the tumour Of these there was one sarcoma patient who had chondro-sarcoma

5 3 6 General symptoms

Slight fever was a symptom in 9 (2 8 %) of the sarcoma patients and 90 (16 3 %) of the myeloma patients Local inflammation occurred in 12 (3 8 %) of the sarcoma patients and in 130 (23 %) of the myeloma patients Oedema at the site of the tumour was a symptom in 234 patients (26 9 %) of whom 106 (33 5 %) were sarcoma patients and 128 (23 1 %) myeloma patients Haemorrhage was a symptom in 87 patients (10 0 %) 2 of whom (0 6 %) were sarcoma patients and 85 (15 4 %) myeloma patients

5 3 7 Lack of symptoms

There were 12 patients (1 4 %) who had no symptoms Two of these had primary chondro sarcoma one had secondary chondro sarcoma and one had chordoma Four multiple myeloma patients and two extra medullary plasma-cytoma patients had no symptoms

Table 15 Histological distribution sex distribution and average age of 869 patients suffering from primary malignant bone tumours

Type of tumour	Patients		Male		Female		Average age
	No	%	No	%	No	%	years
Bone-forming tumours							
Osteo-sarcoma	123	14 2	73	59 3	50	40 7	31 7
Parosteal osteo sarcoma	4	0 5	1	25 0	3	75 0	22 0
Cartilage-forming tumours							
Primary chondro-sarcoma	53	6 1	31	58 5	22	41 5	42 6
Secondary chondro-sarcoma	15	1 7	7	46 7	8	53 3	45 8
Giant-cell tumours							
Malignant giant cell tumour	25	2 9	10	40 0	15	60 0	36 0
Bone-marrow tumours							
Ewing s sarcoma	18	2 1	8	44 4	10	55 6	19 1
Reticulum-cell sarcoma	14	1 6	6	42 9	8	57 1	46 1
Lympho sarcoma	6	0 7	6	100 0			47 9
Solitary myeloma	10	1 1	5	50 0	5	50 0	54 1
Type NUD	8	0 9	4	50 0	4	50 0	50 2
Type IgG	2	0 2	1	50 0	1	50 0	69 5
Multiple myeloma	533	61 3	250	46 9	283	53 1	64 5
Type NUD	42	4 8	17	40 5	25	59 5	63 9
Type IgA	129	14 8	60	46 5	69	53 5	63 9
Type IgG	359	41 3	171	47 6	188	52 4	65 1
Type IgM	3	0 3	2	66 7	1	33 3	66 2
Extra medullary plasma-cytoma	10	1 1	7	70 0	3	30 0	58 1
Type NUD	9	1 0	7	77 8	2	22 2	56 9
Type IgA	1	0 1			1	100 0	68 8
Vascular tumours							
Angio sarcoma	4	0 5	3	75 0	1	25 0	44 5
Haemangiopericytoma sarcoma	2	0 2	2	100 0			36 1
Other connective-tissue tumours							
Fibro-sarcoma	14	1 6	10	71 4	4	28 6	47 1
Primary malignant fibrous-histio cytoma	9	1 0	5	55 6	4	44 4	42 5
NUD sarcoma	18	2 1	12	66 7	6	33 3	56 4
Radiation sarcoma	2	0 2			2	100 0	53 8
Fibrolipo myxoma malignum	1	0 1	1	100 0			58 6
Condro-myxoma malignum	1	0 1	1	100 0			66 2
Fibro-myxoma malignum	1	0 1			1	100 0	60 7
Other tumours							
Chordoma	5	0 6	3	60 0	2	40 0	60 1
Neuro-sarcoma	1	0 1	1	100 0			34 0
Total	869	99 8	442	50 9	427	49 2	54 7

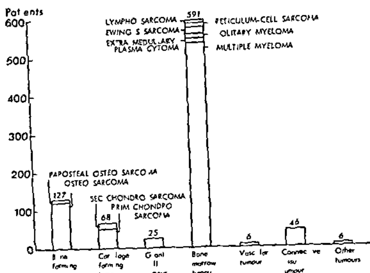


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Pubis	Ischii	Femur	Tibia	Fibula	Ossa tarsii	Ossa metatars	Phal ped	Humerus	Radius	Ulna	Ossa carpi	Ossa meta carp	Phal man	Patella
1	4	44	20	9				13	1					
		1	1											
2		14	7					1	2			1	1	
1		3	1					3				1	1	
	1	11	3	1	1		1		2			1		
		2	5					2						
1	1	4				1								
		1	1					1						
		1												
13	11	19	2					10	1	1				
33	38	52	9	3				33	8	7			1	3
135	133	153	6	17	[illegible]	2	3	105	25	19	5	4	3	1
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									1					
		7	2					2				1		
		2	2	1				1						
	1	4	1					1						
		1												
		1												

months) primary chondro-sarcoma (13 0 months) secondary chondro sarcoma (16 7 months) malignant giant-cell tumours (17 9 months) chordoma (11 months) and extra medullary plasma cytoma (11—24 months)

No information was available for the *duration* of symptoms in 19 patients

5 4 FTIOLOGY

It was not possible in this study to demonstrate any hereditary factor in the de-

Table 16 Skeletal distribution of 869 primary malignant bone tumours

Type of tumour	Total	Skull	Mandi bula	C 1— C7	Th 1— Th 12	L 2— L 5	S 1— S 4	Ster num	Clavi cula	Cos[illegible] 1–[illegible]
Bone-forming tumours										
Osteo-sarcoma	123	6	4	1	1	2	2	1	1	[illegible]
Parosteal osteo sarcoma	4		1		1					
Cartilage forming tumours										
Primary chondro-sarcoma	53	2			1	1	3	2	1	[illegible]
Secondary chondro-sarcoma	15				1				1	[illegible]
Giant-cell tumours										
Malignant giant cell tumour	25		1		2		1			
Bone marrow tumours										
Ewing s sarcoma	18					4				[illegible]
Reticulum cell sarcoma	14				1	3		1		
Lympho-sarcoma	6				1					
Solitary myeloma										
Type NUD	8				3		1	1		[illegible]
Type IgG	2					2				
Multiple myeloma										
Type NUD	42	22	4	3	14	13	1	4	7	13
Type IgA	129	91	16	12	48	44	10	9	23	31
Type IgG	359	249	61	43	143	137	24	21	64	[illegible]
Type IgM	3	2	1	2	1	2	1	1	1	[illegible]
Extra medullary plasma cytoma										
Type NUD	9									
Type IgA	1									
Vascular tumours										
Angio sarcoma	4	1			1					
Haemangio pericytoma-sarcoma	2									
Other connective-tissue tumours										
Fibro-sarcoma	14		1				1		1	1
Primary malignant fibroushistio cytoma	9		1							
NUD sarcoma	18		1		2			1	1	
Radiation sarcoma	2									
Fibrolipo myxoma malignum	1									
Condro-myxoma malignum	1									
Fibro myxoma malignum	1	1								
Other tumours										
Chordoma	5	1				1	3			
Neuro sarcoma	1					1				

5 3 8 Duration of symptoms

The average duration of symptoms before diagnosis was 7 2 months Symptoms had lasted for less than six months in patients with *osteo-sarcoma* reticulum-cell sarcoma lympho sarcoma fibro-sarcoma primary fibrous histio-cytoma also in cases of myeloma (with the exception of solitary myeloma) and extra-medullary plasma cytoma Symptoms had lasted longer in patients with parosteal osteo-sarcoma (15 3

Table 17 X ray findings for 869 primary malignant bone tumours

Type of tumour	Plain radiography		Angiography		Tomography	
	Diagn	Norm	Diagn	Norm	Diagn	Norm
Bone forming tumours						
Osteo sarcoma	11[illegible]	2	24	3	21	1
Parosteal osteo sarcoma	4		1		1	
Cartilage forming tumours						
Primary chondro sarcoma	47	1	11		11	
Secondary chondro-sarcoma	17	1		1	5	
Giant-cell tumours						
Malignant giant cell tumour	21		2	2	6	
Bone marrow tumours						
Ewing s sarcoma	16	1			2	
Reticulum-cell sarcoma	11		2		4	
Lympho sarcoma	6				2	
Solitary myeloma	10				6	
Multiple myeloma	445	6[illegible]	1	4	42	5
Extra medullary plasma-cytoma	1	1	1			
Vascular tumours						
Angio-sarcoma	4				1	
Haemangio-pericytoma sarcoma	2				1	
Other connective tissue tumours						
Fibro-sarcoma	1[illegible]	2	1		3	
Primary malignant fibrous histio cytoma	9		1		6	
NUD sarcoma	18		2	1		
Radiation sarcoma	2		1		2	
Fibrolipo myxoma malignum	1				1	
Chondro-myxoma malignum	1				1	
Fibro-myxoma malignum	1		1		1	
Other tumours						
Chordoma	5		1			
Neuro-sarcoma	1					
Total	746	70	49	11	116	6

velopment of primary malignant bone tumours neither could it be proved that trauma had anything to do with the growth of the tumour Radiation sarcoma was confirmed in two female patients One of these had been given radiation treatment for tuberculosis of the knee and the other had had radiation treatment in the humerus radiation sarcoma subsequently developed at these sites There was one case where fibro-sarcoma had developed as a result of Paget s disease

5 5 LOCATION

The location of tumours is shown in Table 16 and Figures 21—35 Extra-medullary plasma-cytoma was in five patients located in the nose in two patients in the hypo-pharynx in one in the sinus maxillaris there was also one case where the tumour was in the orbit and another in which it was situated in the inguinal nodule

5 6 DISCUSSION

The 10^5 incidence of primary malignant bone tumours was 2 84 new tumours annually and bone tumours accounted for 1 28 % of all malignant tumours These figures correspond roughly to those published elsewhere (Swedish Cancer Registry 1960 The Cancer Registry of Norway 1964 Copeland 1967 Bristol Registry 1971)

Histological distribution was similar to that in earlier studies There were no cases of the following rare tumours juxta-cortical chondro-sarcoma mesenchymal chondro-sarcoma lipo-sarcoma malignant mesenchymoma undifferentiated sarcoma and adamantinoma of long bones The Finnish classification included also secondary chondro-sarcoma solitary myeloma, extra-medullary plasma-cytoma, haemangio-pericytoma-sarcoma radiation sarcoma, primary malignant fibrous histio-cytoma NUD sarcoma, fibrolipo-myxoma malignum, chondro-myxoma malignum and fibro-myxoma malignum

Pain was the most common symptom and it occurred in 88 6 % of the patients It was at first considered to be neurological or referred pain in 71 6 % of the patients It was not possible in the present study to show that trauma played any part in the etiology of primary malignant bone tumours Symptoms on the whole had lasted rather a short time when the diagnosis was made 7 2 months on the average Diagnosis was delayed in only three cases

5 7 X-RAY FINDINGS

5 7 1 Plain radiography

Plain radiography was carried out before treatment on 816 patients (93 9 %) in order to discover whether there were changes in the bone In 746 cases (91 4 %) the result of this examination was concordant with the presence of malignant tumour The X-ray was interpreted as normal in 70 cases (8 6 %) Of the sarcoma patients 290 (97 6 %) were found in the X-ray examination to have symptoms concordant with malignant bone tumour The corresponding figures for myeloma patients were 456 (87 9 %)

5 7 2 Angiography

Angiography was performed on 60 patients (6 9 %) The result of the examina

Table 17 X ray findings for 869 primary malignant bone tumours

Type of tumour	Plain radiography		Angiography		Tomography	
	Diagn.	Norm	Diagn	Norm.	Diagn	Norm
Bone forming tumours						
Osteo-sarcoma	112	2	24	3	21	1
Parosteal osteo sarcoma	4		1		1	
Cartilage-forming tumours						
Primary chondro-sarcoma	47	1	11		11	
Secondary chondro-sarcoma	17	1		1	5	
Giant-cell tumours						
Malignant giant cell tumour	21		2	2	6	
Bone marrow tumours						
Ewing's sarcoma	16	1			2	
Reticulum-cell sarcoma	11		2		4	
Lympho sarcoma	6				2	
Solitary myeloma	10				6	
Multiple myeloma	445	62	1	4	42	5
Extra medullary plasma cytoma	1	1	1			
Vascular tumours						
Angio-sarcoma	4				1	
Haemangio-pericytoma sarcoma	2				1	
Other connective tissue tumours						
Fibro sarcoma	12	[illegible]	1		3	
Primary malignant fibrous histio-cytoma	9		1		6	
NUD sarcoma	18		2	1		
Radiation sarcoma	[illegible]		1		2	
Fibrolipo myxoma malignum	1				1	
Chondro-myxoma malignum	1				1	
Fibro-myxoma malignum	1		1		1	
Other tumours						
Chordoma	5		1			
Neuro sarcoma	1					
Total	746	70	49	11	116	6

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Pain was the most common symptom and it occurred in 88 6 % of the patients It was at first considered to be neurological or referred pain in 71 6 % of the patients It was not possible in the present study to show that trauma played any part in the etiology of primary malignant bone tumours Symptoms on the whole had lasted rather a short time when the diagnosis was made 7 2 months on the average Diagnosis was delayed in only three cases

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5 7 2 Angiography

Angiography was performed on 60 patients (6 9 %) The result of the examina-

loma patients (87 9 %) 56 of these patients (11 5 %) came for a further examination

5 8.3 Study of frozen sections

Study of frozen sections was carried out on 41 sarcoma patients in connection with surgery In six cases (14 6 %) the tumour was considered to be benign in the light of this study In the remaining 35 cases (85 4 %) the study of frozen sections revealed the presence of malignant tissue

5 8 4 Confirmation of diagnosis

Diagnosis was considered to be confirmed if the result of the histo pathological examination was certain In cases of myeloma the diagnosis was considered to be confirmed if there was either a clear histo pathological diagnosis or if X ray findings and laboratory findings together with the clinical picture were concordant with such a diagnosis Only a few marrow smears were available for the present study because haematological laboratories do not keep such samples for long

5 8 5 Discussion

A frozen section taken during surgery may sometimes be helpful but generally the diagnosis should be made before surgery is embarked upon radiologically and with the aid of histological examination of adequate biopsy specimens In the present series a frozen section was examined in 41 cases and malignancy was confirmed in 85 4 % of these cases

5 9 LABORATORY TESTS

Laboratory findings are shown in Figure 3

Table 18 SR values for 850 sarcoma and myeloma patients

S R mm/h	Sarcoma patients %	Myeloma patients %
1—19	49 4	5.5
20—49	30 2	13 8
50—99	15 6	26 4
$\geq$ 100	4 9	54.3

5 9 1 Discussion

Laboratory findings are important in diagnosing primary malignant bone tumours and especially when studying the degree of spreading The laboratory tests required in the diagnosis of bone sarcomas are very simple and are easy to carry out in any hospital In the present study the blood group distribution was approximately the same as in the study by Nevanlinna (1973)

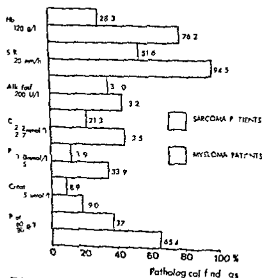


Figure 3 Pathological laboratory findings (%) for sarcoma and myeloma patients

tion was concordant with the presence of malignant bone tumour in 47 of the sarcoma patients (87 0 %) For myeloma patients the figure was 33 3 %

5 7 3 Lymphography

Lymphography was performed on 5 patients (0 6 %) The examination showed that the tumour had spread into the lymphatic ducts in one (25 %) of the sarcoma patients Lymphography was performed on one myeloma patient who was suffering from extra-medullary plasma-cytoma and it was found that the tumour had reached the lymph nodes

5 7 4 Other examinations

Scintigraphy was performed on 26 patients (3 0 %) It was found in 13 (76 5 %) of the patients with sarcoma that isotope had collected in the bone at the place revealed in the X-ray examination In all the nine myeloma patients examined it was found that isotope had collected

Tomography was performed on 122 patients (14 3 %) and the result was concordant with the presence of primary malignant bone tumour in 68 of the 69 sarcoma patients (98 6 %) For myeloma patients 48 of 53 examinations (90 6 %) were positive

Neither computer tomography nor thermography were performed for the present study

5 7 5 Discussion

The final radiological diagnosis was poss ble when using ordinary radiographs in 91 4 % of cases which is in accord with findings reported elsewhere (Lodwick 1967 Ranke 1968)

Angiography was usually helpful for determining the extent of the tumour outside the bone involved Angiography may also be helpful for differentiating chondrosarcoma from benign osteo-chondroma but in general it does not seen to help when trying to distinguish between benign and malignant bone lesions (Yaghmai 1979) It is valuable in preoperative planning particularly in the case of malignant tumours of the pelvis

Scintigraphy is an important method for revealing primary malignant bone tumours Because the series studied consists of cases in the nineteen-sixties scintigraphy was used in only 26 cases No conclusions concerning its value can therefore be drawn It does however seem to be of great value for detecting local bone marrow and distant metastases It is very useful in postoperative follow-up

The significance of lymphography is widely recognized and it is used increasingly in planning treatment for primary malignant bone tumours

5 8 HISTO-PATHOLOGICAL EXAMINATION AND CONFIRMATION OF DIAGNOSIS

5 8 1 Sarcoma patients

A histological diagnosis of every sarcoma patient in the present study was supplied by an expert pathologist Samples from 261 patients (82 3 %) were available for this study

5 8 2 Myeloma patients

A diagnosis by a specialist either histopathological or on the basis of a marrow smear was supplied for 486 of the mye

Evacuation			Radiation treatment		Cytostat treatment	No specific treatment	Total
No rad.	Rad.	Other		Cytostat			
	5	1	22	4	3	8	123
							4
			16	3		3	53
			3				15
4							
4	2		4			2	25
			5	2	1	1	18
			7	2		3	14
			1	2			6
			3	2		2	10
			4			1	10
			[illegible]			1	4
			1				2
			4		1	1	14
			1	1	1	1	9
			7	2		5	18
							2
							1
							1
							1
						2	5
				1			1
8	9	1	80	19	6	30	336

If we consider the whole series (with the exception of patients suffering from multiple myeloma) the figures for different types of treatment are the following 139 patients out of 336 (41 4 %) were treated with radical surgery 62 patients (18 5 %) were treated with non radical surgery 80 (23 8 %) were given radiation treatment 19 (5 7 %) were given radiation treatment and cytostat treatment 6 (1 8 %) received cytostat treatment and for 30 patients (8 9 %) no specific treatment was possible

Of the myeloma patients 334 (62 7 %)

Table 19 Treatment of 336 patients suffering from primary malignant bone tumour (multiple myeloma patients excluded)

Type of tumour	Radical ablative surgery			Radical resection			Local resection		
	No rad	Rad	Other	No rad	Rad	Other	No rad	Rad	Other
Bone forming tumours									
Osteo-sarcoma	24	32	8	1	8	1		6	
Parosteal osteo-sarcoma	1			1	1			1	
Cartilage-forming tumours									
Primary chondro-sarcoma	10	5	5	4		1	3	1	2
Secondary chondro sarcoma		2			1	2	1	1	1
Giant cell tumours									
Malignant giant cell tumour	3	1	2	3	1			3	
Bone-marrow tumours									
Ewing s sarcoma	1	2	3					2	1
Reticulum cell sarcoma		1					1		
Lympho-sarcoma	1			1				1	
Solitary myeloma							1	2	
Multiple myeloma									
Extra-medullary plasma cytoma							2	3	
Vascular tumours									
Angio-sarcoma							1		
Haemangio-pericytoma-sarcoma							1		
Other connective tissue tumours									
Fibro sarcoma	1		2		1			2	
Primary malignant fibrous histio-cytoma	2				2			1	
NUD sarcoma		1		1	1		1		
Radiation sarcoma	1		1						
Fibrolipo myxoma malignum								1	
Chondro myxoma malignum							1		
Fibro myxoma malignum								1	
Other tumours									
Chordoma									
Neuro sarcoma							3		
Total	44	44	21	11	15	4	15	25	4

5 10 TREATMENT

Treatment of patients is shown in Tables 19 and 20 and also in appendix 9 2 Of the osteo-sarcoma patients 74 (60 2 %) were treated by means of radical surgery It proved possible to treat 30 (44 1 %) of the chondro-sarcoma patients by means of radical surgery The corresponding figure for giant-cell tumours was 10 (40 0 %) Of the Ewing s-sarcoma patients it was possible to treat six (33 3 %) by means of radical surgery In the case of other tumours radical surgery was less frequent

Evacuation			Radiation treatment		Cytostat treatment	No specific treatment	Total
No rad	Rad	Other		Cytostat			
	5	1	22	4	3	8	123
							4
			16	3		3	53
							15
4			3				
4	2		4			2	25
			5	2	1	1	18
			7	2		3	14
			1	2			6
			3	2		2	10
			4			1	10
			2			1	4
			1				2
	2		4		1	1	14
			1	1	1	1	9
			7	2		5	18
							2
							1
							1
							1
						2	5
				1			1
8	9	1	80	19	6	30	336

If we consider the whole series (with the exception of patients suffering from multiple myeloma) the figures for different types of treatment are the following 139 patients out of 336 (41 4 %) were treated with radical surgery 62 patients (18 5 %) were treated with non radical surgery 80 (23 8 %) were given radiation treatment 19 (5 7 %) were given radiation treatment and cytostat treatment 6 (1 8 %) received cytostat treatment and for 30 patients (8 9 %) no specific treatment was possible

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Table 19 Treatment of 336 patients suffering from primary malignant bone tumour (multiple myeloma patients excluded)

Type of tumour	Radical ablative surgery			Radical resection			Local resection		
	No rad	Rad	Other	No rad	Rad	Other	No rad	Rad	Other
Bone-forming tumours									
Osteo sarcoma	24	32	8	1	8	1		6	
Parosteal osteo sarcoma	1			1	1			1	
Cartilage-forming tumours									
Primary chondro-sarcoma	10	5	5	4		1	3	1	2
Secondary chondro sarcoma		2			1	2	1	1	1
Giant cell tumours									
Malignant giant cell tumour	3	1	2	3	1			3	
Bone marrow tumours									
Ewing s sarcoma	1	2	3					2	1
Reticulum-cell sarcoma		1					1		
Lympho sarcoma	1			1				1	
Solitary myeloma							1	2	
Multiple myeloma									
Extra-medullary plasma cytoma							2	3	
Vascular tumours									
Angio-sarcoma							1		
Haemangio-pericytoma-sarcoma							1		
Other connective tissue tumours									
Fibro-sarcoma	1		2		1			2	
Primary malignant fibrous histio cytoma	2				2			1	
NUD sarcoma		1		1	1		1		
Radiation sarcoma	1		1						
Fibrolipo myxoma malignum								1	
Chondro-myxoma malignum							1		
Fibro myxoma malignum								1	
Other tumours									
Chordoma									
Neuro-sarcoma							3		
Total	44	44	21	11	15	4	15	25	4

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Treatment of patients is shown in Tables 19 and 20 and also in appendix 9 2 Of the osteo-sarcoma patients 74 (60 2 %) were treated by means of radical surgery It proved possible to treat 30 (44 1 %) of the chondro-sarcoma patients by means of radical surgery The corresponding figure for giant cell tumours was 10 (40 0 %) Of the Ewing s-sarcoma patients it was possible to treat six (33 3 %) by means of radical surgery In the case of other tumours radical surgery was less frequent

Evacuation			Radiation treatment		Cytostat treatment	No specific treatment	Total
No rad.	Rad.	Other		Cytostat			
	5	1	22	4	3	8	123
							4
			16	3		3	53
4			3				15
4	2		4			2	25
			5	2	1	1	18
			7	2		3	14
			1	2			6
			3	2		2	10
			4			1	10
			2			1	4
			1				2
			4		1	1	14
			1	1	1	1	9
			7	2		5	18
							2
							1
							1
							1
						2	5
				1			1
8	9	1	80	19	6	30	336*

If we consider the whole series (with the exception of patients suffering from multiple myeloma) the figures for different types of treatment are the following 139 patients out of 336 (41 4 %) were treated with radical surgery 62 patients (18 5 %) were treated with non radical surgery 80 (23 8 %) were given radiation treatment 19 (5 7 %) were given radiation treatment and cytostat treatment 6 (1 8 %) received cytostat treatment and for 30 patients (8 9 %) no specific treatment was possible

Of the myeloma patients 334 (62 7 %)

Table 20 Treatment of 533 patients suffering multiple myeloma

Type of treatment	Subgroups of myeloma				Total No
	NUD	IgA	IgG	IgM	
Cytostat treatment	7	29	93	2	131
Survival rate more than 5 years	0	1	9	0	
Average age years	65 2	61 5	63 8	65 5	
Survival rate years	0 6	0 6	1 0	2 2	
Cytostat + radiation	7	23	59	1	90
Survival rate more than 5 years	0	0	4	0	
Average age years	60 2	61 3	61 6	68 1	
Survival rate years	1 6	1 6	1 5	0 6	
Cytostat + cortisone	2	17	59		78
Survival rate more than 5 years	0	0	3		
Average age years	47 6	66 8	64 0		
Survival rate years	1 0	1 0	1 0		
Urethane	1	10	24		35
Survival rate more than 5 years	0	0	0		
Average age years	66 3	64 6	64 1		
Survival rate, years	0 1	0 3	1 1		
Radiation treatment	7	8	17		32
Survival rate more than 5 years	0	0	0		
Average age years	67 3	60 6	65 2		
Survival rate years	0 5	1 1	0 9		
Radiation + cortisone			9		9
Survival rate more than 5 years			0		
Average age years			56 2		
Survival rate years			1 9		
Cortisone	3	12	9		24
Survival rate more than 5 years	0	0	0		
Average age years	65 8	66 3	69 7		
Survival rate years	0 3	0 3	0 5		
Testosterone		2			2
Survival rate more than 5 years		0			
Average age years		66 1			
Survival rate years		0 3			
Fluoride		2			2
Survival rate more than 5 years		0			
Average age years		71 4			
Survival rate years		1 3			
General treatment	15	26	89		130
Survival rate more than 5 years	0	0	2		
Average age years	64 7	68 5	75 9		
Survival rate years	0 7	0 6	0 5		
					533

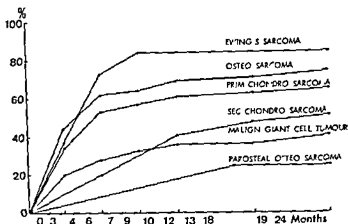


Figure 4 The development of metastases as a function of time in osteo-sarcoma, parosteal osteo-sarcoma primary and secondary chondro-sarcoma, malignant giant-cell tumour and Ewing s sarcoma.

were given cytostat treatment 131 (24 6 %) received radiation treatment and 28 (5 3 %) other treatment 130 (24 4 %) of these patients received basic treatment

In the present study the radiation referred to is roentgen therapy only very few patients received megavolt therapy The radiation dose was 200 rad per day For Ewing s sarcoma the dose was 5 500—8 200 rad. for reticulum-cell sarcoma 2 400—6 800 rad and for lympho-sarcoma 4 000—6 000 rad

The cytostatic agents used were cyclophosphamide methotrexate melphalan and ethyl carbamate Treatment with massive doses of three or four different cytostatic agents was not used

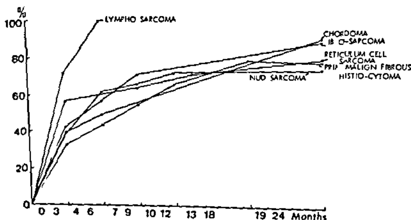


Figure 5 Development of metastases in reticulum-cell sarcoma, fibro-sarcoma, chordoma malignant fibrous histio-cytoma and NUD sarcoma.

5 11 PROGNOSIS

5 11 1 Metastases

More than 50 % of sarcoma patients had metastases within six months of presenting themselves for treatment, with the exception of those suffering from secondary chondro-sarcoma for whom the figure was 40 % and those suffering from malignant giant-cell tumours, for whom the figure was 32 % Metastases were rather rare after one year (Figures 4 and 5)

5 11 1 1 Discussion

Metastases of primary malignant bone tumours develop rapidly by the haemathogeneous route most frequently in the lungs liver, organs of the abdominal cavity and more rarely in the lymphatic ducts (Sellors 1970, Beck et al 1976 Tallroth 1976) The realization that metastases form quickly has led to the use of modern combined cytostat treatment for many primary malignant bone tumours

5 11 2 Survival

5 11 2 1 Bone forming tumours

5 11 2 1 1 Osteo sarcoma

The 5-year survival rate for osteo-sarcoma was 28 4 % and the 10-year survival rate was 24 8 %

The 5-year survival rate for patients with osteo-sarcoma in the humerus was 7 7 % Only one patient lived more than five years this patient had a tumour in the diaphysis of the humerus which was treated by extirpation and post-operative radiation

For osteo-sarcoma patients whose tumour was in the femur, the 5-year survival rate was 27 3 % The location of the tumour has considerable significance Prognosis is better if a tumour is situated in the distal part of the bone Of those patients who had tumours in the collum or trocanter region of the femur not one lived for five years All those patients with osteo-sarcoma in the femur who lived more than five years, were treated by means of radical amputation

The prognosis for osteo-sarcoma in the tibia is better than for osteo-sarcoma in the other long bones The 5-year survival rate was 45 0 % and the 10-year survival rate was 40 0 % With one exception all those patients who lived for more than five years were treated by means of radical ablative surgery

The results of treatment when the tumour was in the fibula or radius correspond approximately to the above

Prognosis was poor for osteo-sarcoma patients if the tumour was located elsewhere than in the long bones No patient with a tumour in the scapula lived as long as five years and the average period of survival from the moment of diagnosis was 1 1 years For patients with osteo sarcoma in the ribs the prognosis was even worse none surviving longer than 0 4 years

The prognosis for osteo-sarcoma if the tumour is in the pelvis or the spine is poor because radical excision of the tumour is seldom possible

Prognosis was good for the four patients who had osteo-sarcoma in the maxilla All these tumours were treated by means of radical resection and radiation all the patients have survived for more than five years and are still symptom-free

Table 21 Survival rate for 869 patients suffering from primary malignant bone tumours (crude survival)

Type of tumour	Survival					
	0—1 years %	1—2 years %	2—3 years %	3—4 years %	4—5 years %	≥ 10 years %
Bone forming tumours						
Osteo-sarcoma	55 3	38 2	33 3	30 9	28 4	24 8
Parosteal osteo sarcoma	100 0	100 0	100 0	100 0	75 0	75 0
Cartilage forming tumours						
Primary chondro-sarcoma	66 0	49 0	41.5	37 7	35 8	27 3
Secondary chondro-sarcoma	93 3	93.3	86 7	73 3	66 7	58 8
Giant cell tumours						
Malignant giant-cell tumour	80 0	68 0	68 0	68 0	64 0	64 0
Bone marrow tumours						
Ewing s sarcoma	55 6	27 8	16 6	16 6	16 6	16 6
Reticulum cell sarcoma	42 9	35 7	28 9	21 5	21 5	12 9
Lympho-sarcoma	66 7	0 0	0 0	0 0	0 0	0 0
Solitary myeloma	50 0	50 0	50 0	50 0	50 0	25 0
Type NUD						
Type IgG						
Multiple myeloma	38 1	19 1	8 9	6 0	4 8	3 0
Type NUD	26 2	11 9	2.3	2 3	0 0	0 0
Type IgA	36 4	12 3	4 7	3 9	2 3	2 3
Type IgG	40 4	22 6	11 2	7 8	6 4	4.3
Type IgM	33 3	0 0	0 0	0 0	0 0	0 0
Extra medullary plasma cytoma	80 0	80 0	70 0	60 0	50 0	30 0
Type NUD	89 9	89 9	78 7	67 4	56 1	33.3
Type IgA	100 0	0 0	0 0	0 0	0 0	0 0
Vascular tumours						
Angio-sarcoma	25 0	25 0	25 0	[illegible]5 0	25 0	25 0
Haemangio-pericytoma sarcoma	50 0	50 0	50 0	50 0	0 0	0 0
Other connective tissue tumours						
Fibro-sarcoma	50 0	35 7	28 7	21 5	21 5	10 8
Primary malignant fibrous histio-cytoma	66 7	56 0	45 0	33 0	22.2	11 1
NUD sarcoma	33 3	2[illegible] 0	16 5	11 0	11 0	11 0
Radiation sarcoma	0 0	0 0	0 0	0 0	0 0	0 0
Fibrolipo-myxoma malignum	100 0	100 0	100 0	100 0	100 0	100 0
Chondro-myxoma malignum	100 0	100 0	0 0	0 0	0 0	0 0
Fibro-myxoma malignum	100 0	100 0	100 0	100 0	100 0	100 0
Other tumours						
Chordoma	60 0	40 0	40 0	40 0	40 0	0 0
Neuro-sarcoma	100 0	0 0	0 0	0 0	0 0	0 0

5 11 PROGNOSIS

5 11 1 Metastases

More than 50 % of sarcoma patients had metastases within six months of presenting themselves for treatment, with the exception of those suffering from secondary chondro-sarcoma for whom the figure was 40 % and those suffering from malignant giant-cell tumours, for whom the figure was 32 % Metastases were rather rare after one year (Figures 4 and 5)

5 11 1 1 *Discussion*

Metastases of primary malignant bone tumours develop rapidly by the haemathogeneous route, most frequently in the lungs liver organs of the abdominal cavity and more rarely in the lymphatic ducts (Sellors 1970, Beck et al 1976, Tallroth 1976) The realization that metastases form quickly has led to the use of modern combined cytostat treatment for many primary malignant bone tumours

5 11 2 Survival

5 11 2 1 *Bone forming tumours*

5 11 2 1 1 *Osteo sarcoma*

The 5-year survival rate for osteo-sarcoma was 28 4 % and the 10-year survival rate was 24 8 %

The 5-year survival rate for patients with osteo-sarcoma in the humerus was 7 7 % Only one patient lived more than five years this patient had a tumour in the diaphysis of the humerus which was treated by extirpation and post-operative radiation

For osteo-sarcoma patients whose tumour was in the femur, the 5-year survival rate was 27 3 % The location of the tumour has considerable significance Prognosis is better if a tumour is situated in the distal part of the bone Of those patients who had tumours in the collum or trocanter region of the femur not one lived for five years All those patients with osteo-sarcoma in the femur who lived more than five years, were treated by means of radical amputation

The prognosis for osteo sarcoma in the tibia is better than for osteo-sarcoma in the other long bones The 5-year survival rate was 45 0 % and the 10-year survival rate was 40 0 % With one exception all those patients who lived for more than five years were treated by means of radical ablative surgery

The results of treatment when the tumour was in the fibula or radius correspond approximately to the above

Prognosis was poor for osteo-sarcoma patients if the tumour was located elsewhere than in the long bones No patient with a tumour in the scapula lived as long as five years and the average period of survival from the moment of diagnosis was 1 1 years For patients with osteo-sarcoma in the ribs the prognosis was even worse none surviving longer than 0 4 years

The prognosis for osteo-sarcoma if the tumour is in the pelvis or the spine is poor because radical excision of the tumour is seldom possible

Prognosis was good for the four patients who had osteo-sarcoma in the maxilla All these tumours were treated by means of radical resection and radiation all the patients have survived for more than five years and are still symptom free

been developed when the patients in this study were being treated. With three exception all those patients with osteo-sarcoma in long bones who survived for more than five years were treated by means of ablative surgery

The five-year survival rate was particularly bad for patients who had a tumour elsewhere than in long bones The prognosis in this study for patients with tumours in the scapula ribs spine or skull is worse than in the report by Dahlin (1972) The results of treatment for tumours in the mandibula were equally bad and deviated from the results generally reported elsewhere (Garrington et al 1967)

According to the findings of the present study it is possible by means of radiation to slow down the growth of a tumour and prolong the period of survival It was impossible to determine the exact dose of radiation that had been given to each patient.

The prognosis for parosteal osteo-sarcoma is better than for any other primary malignant bone tumour The three patients in this study with parosteal osteo-sarcoma lived for more than ten years This result compares favourably with those in other reports All these patients were treated surgically

5 11 2.2 *Cartilage forming tumours*

5 11 2 2 1 *Primary chondro sarcoma*

The five-year survival rate for primary chondro-sarcoma was 3o 8 % and the 10-year survival rate 27 3 %

The five-year survival rate for patients who had tumours in the femur was 14 3 %. The prognosis for those with tumours in the tibia was the same Those patients with chondro-sarcoma in long bones who lived more than five years were treated with radical surgery One patient with chondro sarcoma in the pelvis who lived more than ten years underwent hemipelvectomy Four of the 11 patients with chondro-sarcoma in the pelvis were treated with radiation and they lived for more than five years

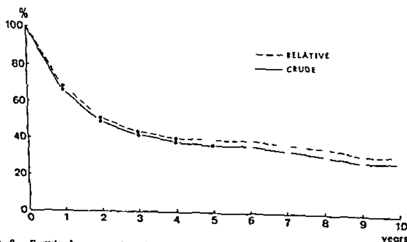


Figure 8 Survival curves for those *suffering* from primary chondro-sarcoma 53 patients (relative and crude survival)

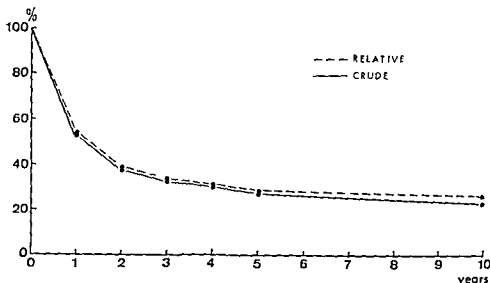


Figure 6 Survival curves for those suffering from osteo-sarcoma 123 patients (relative and crude survival)

The longest period of survival for a patient with osteo-sarcoma in the mandibula was 12 years

5 11 2 1 2 *Parosteal osteo-sarcoma*

The 5-year and 10-year survival rates for parosteal osteo-sarcoma were 75 %

5 11 2 1 3 *Discussion*

The common treatment for osteo-sarcoma in long bones is radical ablative surgery 64 patients (73 6 %) with osteo-sarcoma in long bones were treated by means of radical amputation or ex-articulation Massive cytostat treatment had not yet

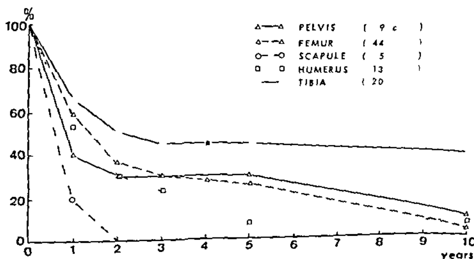


Figure 7 Survival curves for osteo sarcoma patients with tumours in the scapula pelvis and femur (crude survival)

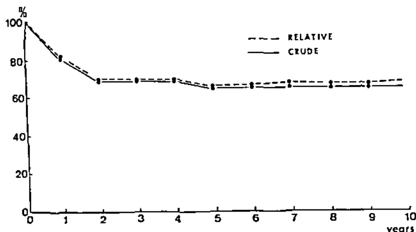


Figure 10 Survival curves for those suffering from malignant giant-cell tumours 25 patients (relative and crude survival)

It is typical of Ewing s sarcoma that it develops early metastases and the prognosis is poor In the present series distant metastases developed within nine months in all certified cases Prognosis was best if the tumour was in the tibia the average survival period for such cases being 1 7 years Three patients lived for over five years One with a tumour in the caput humeri was treated with radical radiation The other two had tumours in the femur in one case the tumour was in the distal metaphysis and that patient underwent hemipelvectomy the other patient had a tumour in the diaphysis and the treatment was amputation These results are comparable with what has been reported earlier (McCormack et al 1952

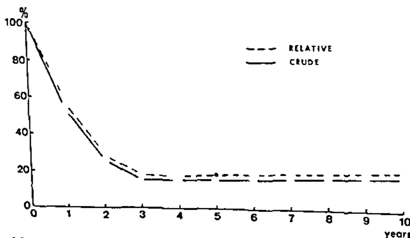


Figure 11 Survival curves for those suffering from Ewing s sarcoma 18 patients (relative and crude survival)

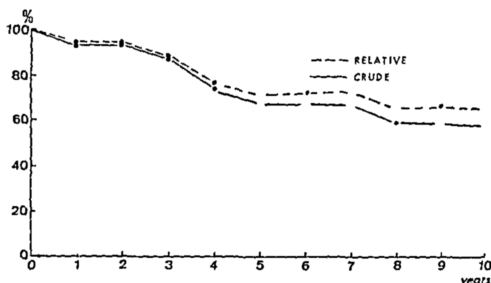


Figure 9 Survival curves for those suffering from secondary chondro sarcoma 15 patients (relative and crude survival))

5 11 2 2 2 Secondary chondro sarcoma

The five-year survival rate for secondary chondro-sarcoma was 66 7 % and the ten-year survival rate was 58 8 %

Ten patients survived for more than five years All of these had undergone surgery, four of them radical surgery

5 11 2 2 3 Discussion

In the present study the prognosis for primary chondro-sarcoma was the same as for osteo-sarcoma although it has generally been considered better (Dahlin 1972) The prognosis for secondary chondro-sarcoma *is twice as good as that for primary* chondro-sarcoma The general idea seems to be that the results of treatment for secondary chondro-sarcoma are good in a short term follow-up but bad in a long term follow-up (Lindbom et al 1961 Dahlin 1972) This concept is not borne out by the results of the present study Our findings suggest that in certain cases it may be worth considering whether instead of radical ablative surgery one may not use a less disabling surgical intervention

5 11 2 3 Giant cell tumours

5 11 2 3 1 Malignant giant cell tumour

The five-year survival rate for malignant giant-cell tumours was 64 0 % and the ten-year survival rate was the same

5 11 2 3 2 Discussion

The prognosis for malignant giant cell tumours is good if the primary treatment is radical (Dahlin 1972 Koskinen 1978) The present study showed that in some cases *conservative surgical treatment* was possible Late metastases even after ten years sometimes occur

5 11 2 4 Bone-marrow tumours

5 11 2 4 1 Ewing s sarcoma

Both the five-year and ten year survival rates for Ewing s sarcoma were 16 6 %

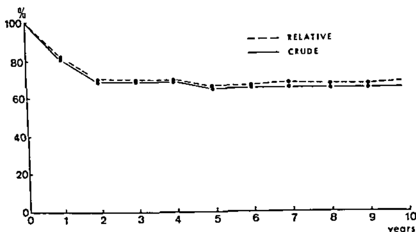


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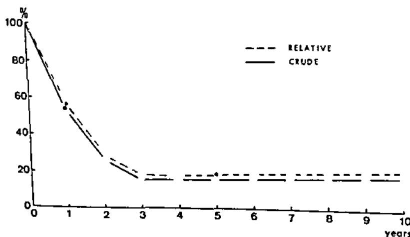


Figure 11 Survival curves for those suffering from Ewing's sarcoma 18 patients (relative and crude survival)

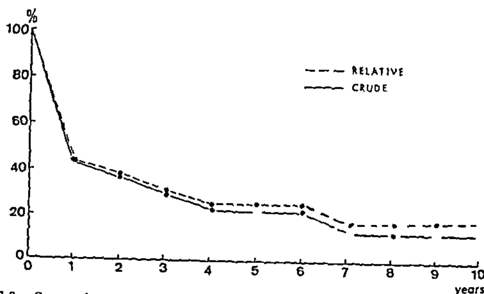


Figure 12 Survival curves for those suffering from reticulum cell sarcoma 14 patients (relative and crude survival)

Wang 1953 Phelan et al 1964, Phillips et al 1967, Dahlin 1972)

5 11 2 4 2 Reticulum-cell sarcoma

The 5-year survival rate for reticulum-cell sarcoma was 21 5 % and the 10-year survival rate was 12 9 %

Three patients who lived more than five years were treated with radiation and with a combination of radiation and cytostats In two cases the tumour was located in the femur and in one in the spine

5 11 2 4 3 Lympho sarcoma

The five-year and ten-year survival rates for lympho-sarcoma were 0 % Not a single patient lived as long as two years from the moment of diagnosis

The treatment of patients suffering from

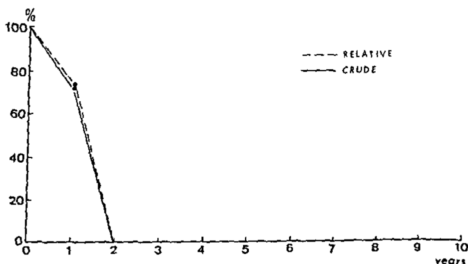


Figure 13 Survival curves for those suffering from lympho sarcoma 6 patients (relative and crude survival)

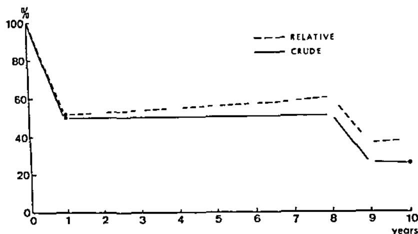


Figure 14 Survival curves for those suffering from solitary myeloma 10 patients (relative and crude survival)

lympho-sarcoma did not differ from that for patients with reticulum cell sarcoma but the prognosis was worse

5 11 2 4 4 *Solitary myeloma*

The five-year survival rate for solitary myeloma were 50 0 % and the ten year survival rate was 25 0 %

Four of the five solitary myeloma patients who lived for more than five years were given radiation treatment Two of them underwent palliative surgery One patient was given anabolic hormones

5 11 2 4 5 *Multiple myeloma*

The five year survival rate for patients suffering from multiple myeloma was 4 8 % and the ten year survival rate was 3 0 %

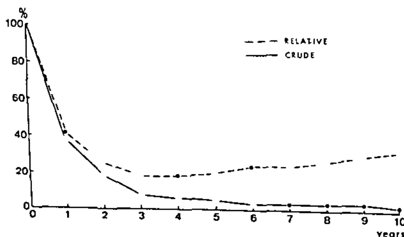


Figure 15 Survival curves for those suffering from multiple myeloma 533 patients (relative and crude survival)

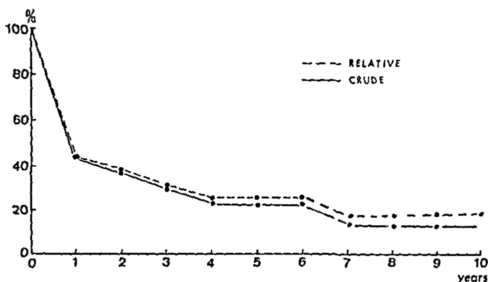


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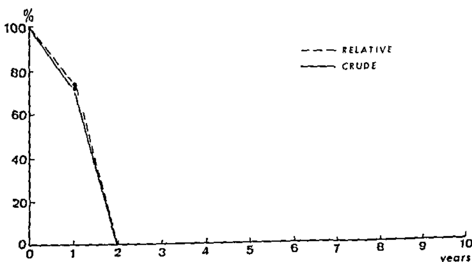


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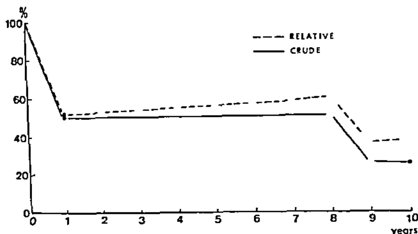


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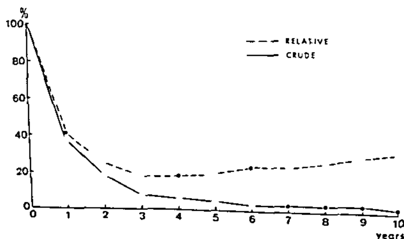


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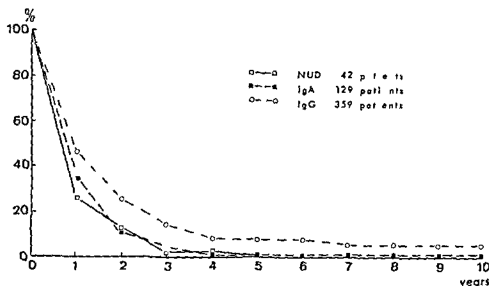


Figure 16 Survival curves for patients suffering from multiple myeloma types NUD IgA and IgG (crude survival)

Of those patients suffering from multiple myeloma 131 (24 6 %) were given cytostat treatment and the five-year survival rate was 7 6 % 90 patients (16 9 %) received cytostat and radiation treatment the five-year survival rate being 4 4 % 78 patients (14 6 %) received cytostat and cortisone treatment, the five-year survival rate being 3 8 % Of those patients who received radiation cortisone urethane anabolic hormone and radio-active fluoride treatment or a combination of these, not one lived for five years Of the 130 patients (24 4 %) who received basic treatment two patients lived more than five years

The average survival periods were 0 7 years for the NUD type 0 8 years for the IgA type 1 1 years for the IgG type and 0 9 years for the IgM type If we compare different methods of treatment the average period of survival when a combination of cytostat and radiation treatment was used was 1 6 years for cases of IgG myeloma the average period of survival when radiation and cortisone treatment were combined was 1 9 years However these figures are not statistically significant owing to the small number of patients involved (9) With all other methods of treatment the average period of survival was less than one year

5 11 2 4 6 *Extra medullary plasma cytoma*

The five-year survival rate for patients suffering from extra-medullary plasmacytoma was 60 % and the ten-year survival rate was 30 0 %

Two of the six extra-medullary plasma-cytoma patients who lived for over five years had been treated surgically and with radiation Two patients were given radiation treatment and one was treated by means of surgical extirpation

5 11 2 4 7 *Discussion*

In the present study the five-year survival rate for Ewing s sarcoma corresponded approximately to that reported by other investigators The basis of present experimental treatment is massive cytostat treatment a combination of three or four

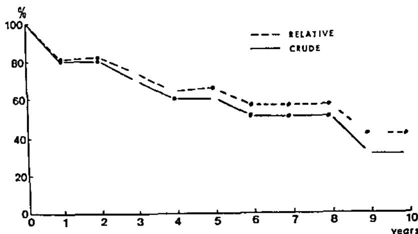


Figure 17 Survival curves for those suffering from extra medullary plasma-cytoma 10 patients (relative and crude survival)

drugs plus surgical and radiation treat ment (Jenkin et al 1976) No other form of treatment is possible because in this disease micro metastases develop early There are as yet no published reports of a long term follow up of patients treated in this way

The results of treatment for reticulum cell sarcoma were clearly worse in this study than in most other reports The average period of survival was 1 5 years Only three of the 14 reticulum-cell sar coma patients lived more than five years Two patients had a tumour in the femur and were treated with radiation one of them was also given cytostat treatment which has been found effective by other investigators (Shoji et al 1971 Dahlin 1972)

In the present study the prognosis for lympho-sarcoma unlike that in other reports (Mincey et al 1974) was exceptionally bad

For myeloma both the treatment given and the prognosis corresponded exactly with what has been reported elsewhere In treating solitary myeloma a combination of surgery and radiation gave good results which corresponds with the picture given by other investigators (Gosepath et al 1969) The results of treatment for multiple myeloma are very poor and the average period of survival as from the moment of diagnosis was less than one year This is about the same as reported elsewhere (Carson et al 1955 Baldwin et al 1967 Dahlin 1972)

The prognosis for extra medullary plasma cytoma is good if the location and spread of the tumour allow radical treatment to be undertaken (Poole et al 1968) In the present study the five-year survival rate was 60 0 % The ten year survival rate was only 30 0 % however which is in keeping with the finding that late metasta ses are common with extra medullary plasma cytoma (Gosepath et al 1969)

5 11 2 5 Vascular tumours

5 11 2 5 1 Angio sarcoma

Of the four patients suffering from angio-sarcoma one lived for over five years

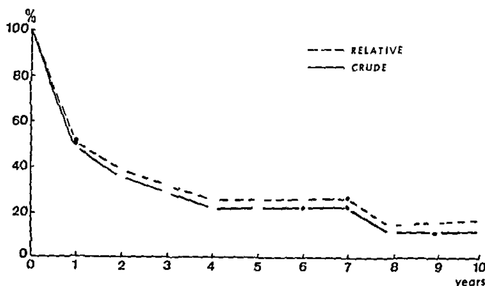


Figure 18 Survival curves for those suffering from fibro sarcoma 14 patients (relative and crude survival)

5 11 2 5 2 Haemangio pericytoma sarcoma

Neither of the two patients suffering from haemangio-pericytoma-sarcoma lived as much as five years

5 11 2 5 3 Discussion

The prognosis for angio-sarcoma and haemangio-pericytoma-sarcoma cannot be established with any certainty on account of the rarity of these tumours The treatment recommended follows the same principles as that for osteo-sarcoma (Dahlin 1972) In the light of the individual cases in the present study it may be said that the tumours are rather malignant Prognosis is very poor

5 11 2 6 Other connective tissue tumours

5 11 2 6 1 Fibro-sarcoma

The 5-year survival rate for patients suffering from fibro-sarcoma was 21 5 % and the ten-year survival rate was 10 8 %

All the fibro-sarcoma patients who lived for more than five years were treated by means of radical surgery and radiation One tumour located in the mandibula was treated by means of local evacuation and radiation

5 11 2 6 2 Primary malignant fibrous histio cytoma

The five-year survival rate for patients suffering from primary malignant fibrous histio-cytoma was 22 2 % and the ten-year survival rate was 11 1 %

Of the nine patients suffering from primary malignant fibrous histio cytoma two lived for more than five years Both were treated by means of radical ablative surgery

5 11 2 6 3 NUD sarcoma

For NUD sarcoma both the five-year and ten-year survival rates were 11 1 %

5 11 2 6 4 Radiation sarcoma

The average period of survival for the two patients in the study was 0 3 years

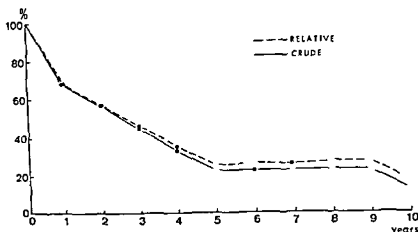


Figure 19 Survival curves for those suffering from primary malignant fibrous histiocytoma 9 patients (relative and crude survival)

5 11 2 6 5 *Fibrolipo myxoma malignum*

The one patient in this study who had fibrolipo myxoma malignum has lived without symptoms for eight years

5 11.2 6 6 *Chondro myxoma malignum*

The only patient in this study who had chondro myxoma malignum lived for 1 5 years after evacuation of a tumour in the trocanter of the femur

5 11 2 6 7 *Fibro myxoma malignum*

The only patient in this study who had a fibro myxoma malignum in the skull lived for 7 4 years after local extirpation and post-operative radiation treatment

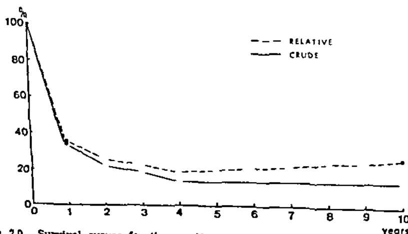


Figure 20 Survival curves for those suffering from NUD sarcoma 18 patients (relative and crude survival)

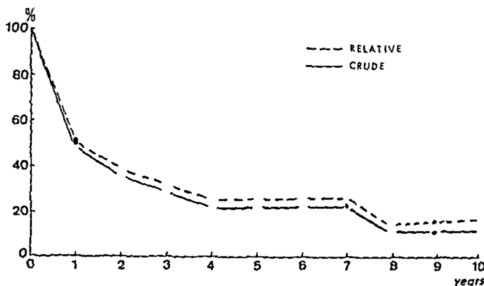


Figure 18 Survival curves for those suffering from fibro sarcoma, 14 patients (relative and crude survival)

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5 11 2 6 3 NUD sarcoma

For NUD sarcoma both the five-year and ten year survival rates were 11 1 %

5 11 2 6 4 Radiation sarcoma

The average period of survival for the two patients in the study was 0 3 years

6 GENERAL DISCUSSION

Between 1962 and 1968 a total of 985 new primary malignant bone tumours were recorded in the Finnish Cancer Registry The clinical follow up comprised 869 patients (88 2 %) there were 316 cases of sarcoma and 553 cases of myeloma In Finland hospitals and departments of pathology are obliged to inform the au thorities if they treat or diagnose malig nant tumours and therefore the figures supplied by the Finnish Cancer Registry may be considered representative of the whole country

The age and sex distribution of the 869 patients with primary malignant bone tu mour included in the clinical study cor responds to that in earlier reports (Dahlin 1972) There were no examples of the very rarest tumours in the present series Pri mary malignant fibrous histio-cytoma was diagnosed in Finland for the first time in this study and there were nine cases The basis for the histo pathological classifica tion was the schema published by the World Health Organization (Schajowicz et al 197?) supplemented by some additional categories for Finnish conditions (Sorvari 19 6)

In bone sarcomas symptoms lasted 4 6 months and in myelomas 6 6 months. There were three cases where the correct diagno sis was not made and the patient received inadequate treatment In many cases the diagnosis was delayed after the primary lesion was detected

A correct radiological diagnosis was made using ordinary radiographs in 91 4 % of cases This corresponds approximately to results reported elsewhere (Lodwick 1967 Ranke 1968)

Angiography was usually helful for determining the extent of the tumour outside the bone involved Angiography may also be helpful for differentiating chondrosarcoma from benign osteo chondroma but in general it does not help when trying to distinguish between benign and malignant bone lesions (Yaghmai 1979) It is valuable in preoperative planning particularly in the case of malignant tumours of the pelvis

Scintigraphy is an important method for revealing primary malignant bone tumours Because the series studied consists of cases in the nineteen sixties scintigraphy was used in only 26 cases No con clusions concerning its value can therefore be drawn It does however seem to be of great value for detecting local bone marrow and distant metastases It is also useful in planning radiographical examinations and in post operative follow up

A frozen section taken during surgery may sometimes be helpful but generally the diagnosis should be made before surgery is embarked upon radiologically and

5 11 2 6 8 Discussion

25 % of fibro-sarcomas are of the secondary type (Dahlin 1972), in the present study there was one fibro-sarcoma which stemmed from Paget s disease The survival rates published here correspond well with those reported elsewhere (Eyre-Brook et al 1969, Dahlin 1972) All the three patients who lived for more than five years were treated surgically and with radiation The treatment for fibro-sarcoma is the same as that for osteo-sarcoma

It is only a few years ago that primary malignant fibrous histio-cytoma was discovered and there is no information about prognosis In the present study it was found to be very malignant and prognosis was worse than for osteo-sarcoma The average period of survival was 1 8 years and the results of treatment were similar to those reported elsewhere (Spanier et al 1975 Slootweg et al 1975 Webber et al 1977)

In the present study NUD sarcoma was considered as a separate disease, because the most precise diagnosis possible in further histo-pathological study was that it was a primary bone tumour of the sarcoma type Prognosis was worse than for osteo-sarcoma and treatment must be as radical as for osteo-sarcoma

Radiation sarcoma fibrolipo-myxoma malignum chondro-myxoma malignum and fibro-myxoma malignum are all rare tumours and there is no precise information about prognosis or treatment Surgical treatment similar to that for osteo-sarcoma is necessary

5 11 2 7 Other tumours

5 11 2 7 1 Chordoma

There were five patients with chordoma in the present study One had a tumour in the spine and lived for 0 6 years and another had a tumour in the skull and lived for 1 3 years Three patients had a tumour in the sacrum two of these were removed surgically and both the patients in question lived for 8 9 years The third who only received basic treatment lived for 0 4 years

5 11 2 7 2 Neuro sarcoma

Only one patient in the present study had neuro-sarcoma The tumour was located in the 4th lumbar vertebra After extirpation of the tumour and post-operative radiation treatment this patient lived for 0 2 years

5 11 2 7 3 Discussion

Because of the anatomical location of the tumour it is seldom possible with chordoma to undertake radical surgery However the tumour grows slowly and thus palliative surgery often gives satis factory results A similar picture is given by Greenwald (1957) and Dahlin (1972) In the present study there was no case in which radical surgery was possible

Neuro-sarcoma is an extremely rare tumour and there are no reports about treatment or prognosis In the light of individual cases it has been considered that treatment should follow the same lines as that for osteo-sarcoma (Guthert 1972)

6 GENERAL DISCUSSION

Between 1962 and 1968 a total of 985 new primary malignant bone tumours were recorded in the Finnish Cancer Registry The clinical follow up comprised 869 patients (88 2 %) there were 316 cases of sarcoma and 553 cases of myeloma. In Finland hospitals and departments of pathology are obliged to inform the au thorities if they treat or diagnose malignant tumours and therefore the figures supplied by the Finnish Cancer Registry may be considered representative of the whole country

The age and sex distribution of the 869 patients with primary malignant bone tumour included in the clinical study cor responds to that in earlier reports (Dahlin 1972) There were no examples of the very rarest tumours in the present series Pri mary malignant fibrous histio cytoma was diagnosed in Finland for the first time in this study and there were nine cases The basis for the histo pathological classification was the schema published by the World Health Organization (Schajowicz et al 1972) supplemented by some additional categories for Finnish conditions (Sorvari 1976)

In bone sarcomas symptoms lasted 4 6 months and in myelomas 6 6 months There were three cases where the correct diagnosis was not made and the patient received inadequate treatment In many cases the diagnosis was delayed after the primary lesion was detected

A correct radiological diagnosis was made using ordinary radiographs in 91 4 % of cases This corresponds approximately to results reported elsewhere (Lodwick 1967 Ranke 1968)

Angiography was usually helful for determining the extent of the tumour out side the bone involved Angiography may also be helpful for differentiating chondrosarcoma from benign osteo chondroma but in general it does not help when trying to distinguish between benign and malignant bone lesions (Yaghmai 1979) It is valuable in preoperative planning particularly in the case of malignant tumours of the pelvis

Scintigraphy is an important method for revealing primary malignant bone tumours Because the series studied consists of cases in the nineteen sixties scintigraphy was used in only 26 cases No con clusions concerning its value can therefore be drawn It does however seem to be of great value for detecting local bone marrow and distant metastases It is also useful in planning radiographical examinations and in post-operative follow up

A frozen section taken during surgery may sometimes be helpful but generally the diagnosis should be made before surgery is embarked upon radiologically and

with the aid of histological examination of adequate biopsy specimens In the present series a frozen section was examined in 41 cases and malignancy was confirmed in 85 4 % of these cases

There were two cases in this series where the malignancy was certainly caused by earlier radiation treatment There was one case where Paget s disease had developed into osteo-sarcoma, this is very rare in Finland The effect of radiation in Paget s disease is well documented (Marie et al 1910, Cohen et al 1948, Esposito et al 1960, MacKenzie et al 1967) Because of the risk involved radiation treatment is no longer used for treating benign bone lesions In the present study there was no case in which trauma could ascertained as *an etiological factor, although it is often* mentioned in literature on the subject (Phemister 1948 Hellner 1966 Fisher 1971)

Laboratory studies for bone sarcomas are simple routine tests and in the present study the results of these tests corresponded to those reported elsewhere (O Hara 1968 Derian et al 1972) Laboratory diagnosis of myeloma has developed rapidly and it was possible to classify 95 2 % of myelomas into immunological sub-groups Laboratory tests are of especial significance in following the progress of primary malignant tumours

In recent years since the practice of extensive bone resections became widespread ablative surgery has been less favoured as a means of treating bone tumours In the present study 64 osteo-sarcoma patients (52 0 %) were treated by means of ablative surgery Radical bone resection was performed in 10 cases Since the period when the patients in this study were undergoing treatment allograft bone transplants and bio-mechanical prostheses have been developed which make possible even more extensive bone resections (Volkov 1970, Parrish 1972, Ottolenghi 1973 Koskinen 1978) Local resection or evacuation proved to be a poor method of treatment, because of recurrence of tumours Evacuation was performed on six patients, many of whom later had to undergo amputation on account of recurrence This experience was similar to that reported by Koskinen (1978)

With the development of surgical and cytostat treatment, the importance of radiation for treating solid bone tumours has diminished in recent years (Koskinen 1976) However, even for osteogenic and chondrogenic tumours which cannot be radically removed, radiation treatment increases the survival time and it is justi*fied as palliative treatment especially* among older patients (Nordman 1979) In our study 99 sarcoma patients were treated with radiation only and it was commonly used as a supplement to surgery

Treatment with cytostatic agents has developed rapidly since the introduction of combined treatment Most patients in this study were given cytostat treatment which consisted of a small dose of a single drug 62 7 per cent of myeloma patients received cytostat treatment in some form

Immunological treatment and interferon are still at the experimental stage (Koskinen 1975 Tallberg 1976 Salenius 1977 Cantell 1978)

The therapy for primary bone sarcomas and multiple myelomas is very different Bone-forming tumours have long been treated by means of ablative surgery when this is anatomically possible The value of ablative surgery is reflected in the higher survival rates for patients with peripheral osteo-sarcomas Thus the five-year survival rate where there were tumours in the tibia was 45 0 % and where

there were tumours in the femur, 27 5 %. The five-year survival rate with humeral osteo sarcomas was only 7 7 % which is lower than that reported by Dahlin (1972) Becaus this group consisted of five cases only and because the therapy was prob ably not quite adequate in all of these cases the difference is not significant

The five year survival rate does not give a dependable picture of parosteal osteosarcoma because of the slow progression of the tumours and late development of metastases (Wolfel et al 1969) There were only four parosteal osteo sarcomas in the present series and it is thus impossible to draw any conclusion

The prognosis for patients with carti lage forming tumours is considered better that for those with osteo sarcomas In the present series the five year survival rate for primary chondro sarcoma was 35 8 % and the ten year survival rate was 27 3 % Henderson and Dahlin (1963) reported a survival rate of 69 2 % in cases treated with adequate surgery No useful conclu sions can be drawn from comparing these results with those of the present study because our patients received different and sometimes also inadequate treatment

The prognosis for malignant giant-cell tumours is good when the primary treatment is radical (Dahlin 1972) Both the five-year and ten year survival rates were treated by means of radical surgery and 64 0 % In the present study eight patients were treated by means of radical surgery and seven by means of local surgery All these patients lived for more than five years The patients who underwent local surgery were all given radiation treat ment

Bone-marrow tumours are usually very malignant primary bone tumours Theo retically massive combined treatment with cytostatic agents is especially indicated in order to destroy micro metastases Particularly in the case of Ewing s sarcoma the results after a short follow up have shown improvement The results of radical ablative surgery are not good In the pre ent study the prognosis for reticulum cell sarcoma was worse than that reported in literature generally The five-year survival rate was 21 5 % only three patients treated with radiation lived for five years although it is generally considered that radiation gives good results in the treatment of reticulum cell sarcoma (Coley et al 1950 Shoji et al 1971 Miller et al 1971) The prognosis for lympho sarcoma was even worse not a single patient surviving for as much as two years This is not as good as results reported elsewhere (Mincey et al 1974)

According to most investigators the best way of treating solitary myeloma is with a combination of surgery and radiation (Dahlin 1972) In individual cases, a period of survival as long as 30 years has been reported (Pancovich et al 1972) In the present study the five-year survival rate was 50 0 % and the ten year survival rate 25 0 % It is known that as the years pass the disease develops into multiple myeloma and for that reason prognosis be comes worse as the follow up time in creases

The prognosis for patients suffering from multiple myeloma is known to be poor few patients surviving more than five years (Copeland 1967 Baldwin et al 1967) In the present study the five-year survival rate was 4 8 % There was no statistically significant difference in these rates when the treatment was a combina tion of different cytostatic agents and cortisone Of the patients who received only basic treatment not one lived for five

years The immunological category to which the tumour belonged had no effect on the prognosis The average period of survival for patients in the present study was as follows IgA myeloma 0 8 years, IgG myeloma 1 1 years, IgM myeloma 0 9 years and NUD myeloma 0 7 years A comparison of the results reveals that after combined cytostat and radiation treatment the period of survival was 1 6 years, whereas a combination of radiation and cortisone when dealing with the IgG type of myeloma gave a survival period of 1 9 years However on account of the small number of patients involved, these figures are not significant statistically

The five-year survival rate for patients suffering from extra-medullary plasmacytoma was 60 0 % and the ten year survival rate was 30 0 % These figures are in accord with what has been stated elsewhere about the development of late metastases (Gosepath et al 1969)

On the basis of individual cases reported in literature on the subject the treatment of and prognosis for primary malignant vascular tumours is the same as for osteo-sarcoma (Dahlin 1972)

In the case of other connective-tissue tumours it is typical that there is osteolytic damage pathological fracture and the development of rather early metastases all of which mean a poor prognosis The five-year survival rate for fibro-sarcoma was 21 5 % which is about the same as that reported in other studies (Gilmer et al 1958 Eyre-Brook et al 1969 Dahlin et al 1969) In the present study those fibro-sarcoma patients who lived for more than five years had been treated surgically and had also had radiation treatment Because of the similar prognosis the principles of treatment for osteo-sarcoma are completely applicable to fibro-sarcoma (Dahlin 1972) On account of its rarity and the small numbers involved, there is very little information about the prognosis and treatment for primary malignant fibrous histio-cytoma In the light of the present study it may be said that it is at least as malignant a tumour as osteo-sarcoma develops metastases just as early and requires similar principles of treatment (Spanier et al 1975 Slootweg et al 1975) The cases reported here are the first primary malignant fibrous histio-cytomas to be diagnosed in Finland Because the prognosis is so bad the NUD-sarcoma cases show convincingly that if it is not possible to achieve a clear histo pathological diagnosis of malignancy the tumour should be treated in the same way as osteo-sarcoma Radiation-sarcoma fibrolipo myxoma malignum chondro-myxoma malignum and fibro-myxoma malignum must also be treated in the same way as osteo-sarcoma

Of those in the final group »other tumours» chordoma is a tumour that grows slowly and can often only be treated palliatively Of the five chordoma patients in this study it was possible to treat only two by means of radical surgery For these the period of survival was 8 9 years whereas the longest period for those who were not operated on radically was 1 3 years Treatment and prognosis for neuro-sarcoma are not well known The general principle of treatment is the same as for osteo-sarcoma (Gilbert 1972)

7 SUMMARY AND CONCLUSIONS

Between the years 1962 and 1968 985 new cases of primary malignant bone tumour were reported by the Finnish Cancer Registry Because hospitals and departments of pathology are obliged to report all new cases to the central authority these figures may be considered representative for the country as a whole Incidence was 3 16 primary malignant bone tumours per 10^5 inhabitants annually Primary malignant bone tumours accounted for 1 25 % of all malignant tumours These figures are comparable to those reported elsewhere (Swedish Cancer Registry 1960 The Cancer Registry of Norway 1964 Bristol Bone Tumour Registry 1971 Ott et al 1977)

The final study comprised 869 patients suffering from primary malignant bone tumour Age and sex distribution was similar to that in earlier studies

Pain at the site of the tumour was the first symptom in 88 6 % of sarcoma patients and 92 4 % of myeloma patients In the case of three patients correct treatment was significantly delayed because of a wrong diagnosis

Plain radiography is the most important form of X ray examination for primary malignant bone tumour Angiography gives additional information that can be used in planning treatment As it develops X ray examination aided by computer will be useful Providing as it does a reasonably sure pre-operative diagnosis this will facilitate the making of decisions about the method of treatment to be adopted

Diagnosis of primary malignant bone tumour should be based on a histological examination In the present series it was shown that study of frozen sections led in 85 4 % of cases to a diagnosis of certain malignancy and was thus valuable for making decisions about treatment.

Tumours were classified as 21 different histological types There were 553 cases of myeloma (63 6 %) 123 cases of osteo-sarcoma (14 2 %) and 68 cases of chondro-sarcoma (7 7 %) These were the most common types

For osteo-sarcoma radical ablative surgery was carried out on 64 patients 32 of whom also had radiation treatment Radical resection was performed on 10 patients eight of whom received radiation treatment Local resection was the treatment for six patients all of whom were also treated with radiation Evacuation was the treatment for six patients five of these also being given radiation treatment Radiation treatment was given to 26 patients four of whom were also treated with cytostatic agents There were eight patients who received no specific treatment either because of their poor general condition or because they refused.

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Metastases developed in more than 50 % of the sarcoma patients within six months Patients suffering from secondary chondro-sarcoma or malignant giant-cell tumours had fewer metastases It was unusual for metastases to develop later than 12 months after patients presented themselves for treatment

The five-year survival rate for osteosarcoma was 28 4 % and the ten-year survival rate was 24 8 % For primary chondro-sarcoma the corresponding figures were 35 8 % and 27 3 % for secondary chondro-sarcoma 66 7 % and 58 8 % The five-year and ten-year survival rates for malignant giant-cell tumours were 64 0 % The corresponding figure for Ewing s sarcoma was 16 6 % For reticulum-cell sarcoma the five-year survival rate was 21 5 % and the ten-year survival rate was 12 9 % No patient suffering from lympho sarcoma lived as long as two years

The average period of survival for patients with multiple myeloma was 0 9 years For those with the IgG type of myeloma the five-year survival rate was 6 4 % and ten-year survival rate was 4 3 % The corresponding figures for other types were worse

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In the light of the present study it may be asserted that because primary malig nant bone tumours are rare and because the symptoms are rather slight diagnosis may be delayed Diagnosis should be based on histological examination and active treatment must be begun at once The use of a combination of cytostatic agents has become an important method of treatment particularly for bone-marrow tumours Malignant fibrous histio-cytoma of the bone now diagnosed in Finland for the first time is a very malignant tumour which must be treated according to the same principles as osteo-sarcoma If it is impossible to achieve an absolutely cer tain diagnosis for a primary bone tumour, but malignancy has been confirmed the procedure for treatment should be as for osteo-sarcoma

Generally speaking these has been a some what pessimistic view of the results of treatment in cases of primary malignant bone tumour The present study shows however that prompt diagnosis and adequate treatment may considerably improve the prognosis and help patients many of whom are younger than in other malig nant diseases If treatment were concen trated in important centres it seems seasnably certain that results would be even better

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9 APPENDIX

9 1 SKELETAL AGE AND SEX DISTRIBUTION OF PRIMARY MALIGNANT BONE TUMOURS ACCORDING TO HISTOLOGICAL DIAGNOSIS 869 CASES FIGS 21—35

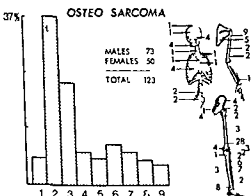


Fig 1 Skeletal age and sex distribution of 123 cases

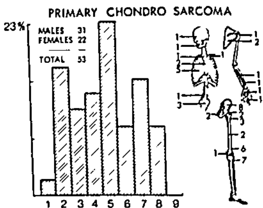


Fig 23 Skeletal age and sex distribution of 53 cases

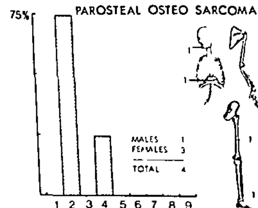


Fig 2 Skeletal age and sex distribution of 4 cases

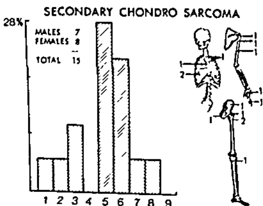


Fig 24 Skeletal age and sex distribution of 15 cases

cial examiner for the thesis and his advice has helped me in many ways

Among the many others who have rendered assistance I cannot omit to thank the following Mr Kari Helander, for familiarizing me with the statistical treatment of the material and looking after the automatic data processing, Mr & Mrs Antony Landon for translating the Finnish manuscript Mrs Kirsti Lundstedt for drawing the pictures Miss Pirjo Rasivaara and Mrs Terttu Kaisti for helping me to assemble material in the early stages the heads of various hospitals and departments for supplying material, the staff of the Turku University medical library fo their courtesy and co-operation

Finally a word of praise for my long suffering family Without the patience and fortitude shown by my wife and children during the long years of waiting it is doubtful whether this book would ever have been completed They have been to me a constant source of inspiration

I am obliged to the Finnish Cancer Society for financial assistance

Helsinki November 1979

Pekka Jussila

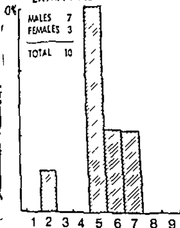


Fig 31 Age and sex distribution of 10 cases

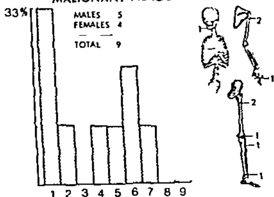


Fig 34 Skeletal age and sex distribution of 9 cases

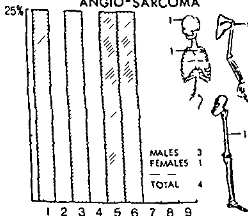


Fig 32 Skeletal age and sex distribution of 4 cases

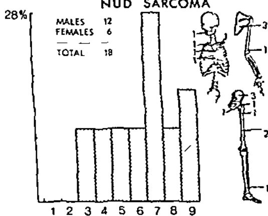


Fig 35 Skeletal age and sex distribution of 18 cases

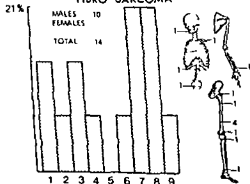


Fig 33 Skeletal age and sex distribution of 14 cases

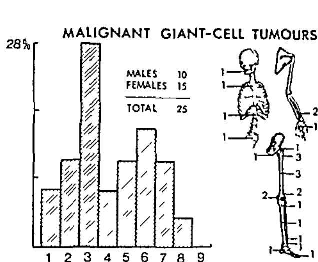


Fig 25 Skeletal age and sex distribution of 25 cases

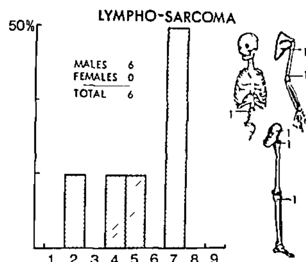


Fig 28 Skeletal age and sex distribution of 6 cases

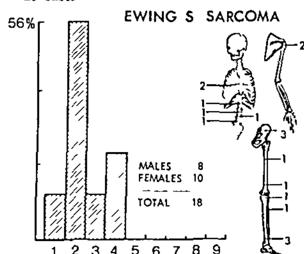


Fig 26 Skeletal age and sex distribution of 18 cases

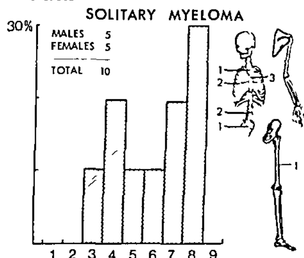


Fig 29 Skeletal age and sex distribution of 10 cases

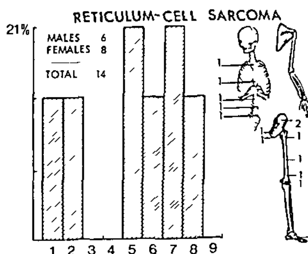


Fig 27 Skeletal age and sex distribution of 14 cases

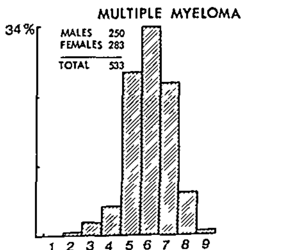


Fig 30 Age and sex distribution of 533 cases

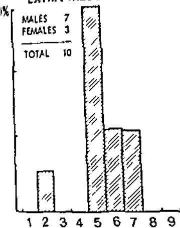


Fig 31 Age and sex distribution of 10 cases

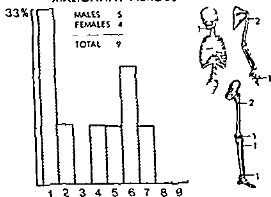


Fig 34 Skeletal age and sex distribution of 9 cases

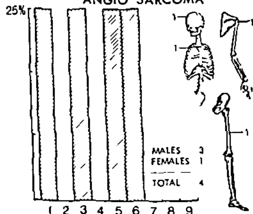


Fig 3? Skeletal age and sex distribution of 4 cases

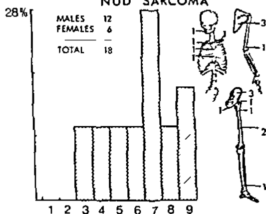


Fig 35 Skeletal age and sex distribution of 18 cases

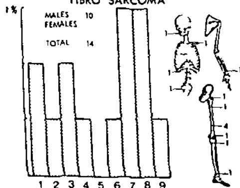


Fig 33 Skeletal age and sex distribution of 14 cases

9 2 CLASSIFICATION OF PATIENTS ACCORDING TO LOCATION OF TUMOUR TREATMENT AVERAGE PERIOD OF SURVIVAL AND AVERAGE AGE 336 CASES

9 2 1 Bone-forming tumours

Table 22 Osteo-sarcoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Rad treatm	4 8	65 6
	1	Basic treatm	0 5	62 7
	2		2 7	64 1
Trochanter	1	Evac + amp	0 3	20 7
	1	Rad treatm	0 5	65 1
	2		0 4	42 9
Diaphysis	1	Preop rad + exartic	0 3	41 7
	1	Amp	L	23 0
	1	Part res + amput	1 1	12 9
	3		0 7	25 9
Metaphysis dist	6	Amp	0 8	17 3
	2	Amp	L	20 2
	1	Exartic	1 7	11 1
	5	Preop rad + amp	1 3	18 5
	1	Preop rad + amp	L	8 8
	1	Amp + evac lymp nodes	0 7	16 9
	1	Amp + postop rad	1 2	19 3
	1	Preop cyt + amp	1 4	16 2
	1	Evac + amp	L	11 4
	1	Preop cyt + amp	L	17 5
	1	Evac + rad	6 2	57 0
	5	Rad treatm	1 0	23 7
	1	Amp + postop rad	L	23 9
	1	Basic treatm	0 8	23 1
	28		1 2	20 3
Epiphysis dist	1	Preop rad + amp	L	17 3
	1	Preop rad + amp	2 0	17 8
	2		2 0	17 6

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Condylus lat.	1	Amp	0 9	21 2
	1	Preop rad + amp	L	20 5
	1	Rad treatm	0 9	16 3
	3		0 9	19 3
Condylus med	2	Amp	2 0	21 2
	1	Amp	L	27 3
	1	Preop rad + amp	L	22 3
	4		1 5	23 0
Tibia				
Condylus lat	1	Preop rad + amp	L	17.2
	1	Preop rad + amp	0 7	14 7
	2		0 7	15 9
Condylus med	1	Amp	1 3	18 3
Metaphysis prox	3	Preop rad + amp	L	13 5
	1	Evac + part res + evac lymph nodes	L	27 9
	1	Evac + postop rad.	1 9	13 0
	1	Rad treatm.	0 3	8 0
	6		1 1	15 1
Diaphysis	1	Amp	6 2	68 8
	1	Amp	L	56 8
	1	Rad + cyt treatm	0 9	16 3
	3		3 7	47 3
Metaphysis dist	1	Amp	L	14 3
	[illegible]	Amp	1 4	16 2
	1	Preop rad + amp	L	12 9
	3	Preop rad + amp	1 2	14 5
	1	Evac + rad	0 9	25 4
	8		1 2	16 0
Fibula				
Metaphysis prox		Amp	L	16 0
	[illegible]	Preop rad + amp	0 6	36 8
	1	Preop rad + loc.res. + amp	2 3	18 6
	1	Amp + postop rad	2 4	18 8
	1	Basic treatm.	0 4	81 0
	7		1 2	32 0
Metaphysis dist.	1	Amp	I	21 0
	1	Evac + amp	1 8	30 2
	-		1 8	[illegible]

9 2 CLASSIFICATION OF PATIENTS ACCORDING TO LOCATION OF TUMOUR TREATMENT, AVERAGE PERIOD OF SURVIVAL AND AVERAGE AGE, 336 CASES

9 2 1 Bone forming tumours

Table 22 Osteo sarcoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Rad treatm	4 8	65 6
	1	Basic treatm	0 5	62 7
	2		2 7	64 1
Trochanter	1	Evac + amp	0 3	20 7
	1	Rad treatm	0 5	65 1
	2		0 4	42 9
Diaphysis	1	Preop rad + exartic	0 3	41 7
	1	Amp	L	23 0
	1	Part res + amput	1 1	12 9
	3		0 7	25 9
Metaphysis dist	6	Amp	0 8	17 3
	2	Amp	L	20 2
	1	Exartic	1 7	11 1
	5	Preop rad + amp	1 3	18 5
	1	Preop rad + amp	L	8 8
	1	Amp + evac lymp nodes	0 7	16 9
	1	Amp + postop rad	1 2	19 3
	1	Preop cyt + amp	1 4	16 2
	1	Evac + amp	L	11 4
	1	Preop cyt + amp	L	17 5
	1	Evac + rad	6 2	57 0
	5	Rad treatm	1 0	23 7
	1	Amp + postop rad	L	23 9
	1	Basic treatm	0 8	23 1
	28		1 2	20 3
Epiphysis dist	1	Preop rad + amp	L	17 3
	1	Preop rad + amp	2 0	17 8
	2		2 0	17 6

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Condylus lat.	1	Amp	0.9	21.2
	1	Preop rad + amp	L	20.5
	1	Rad treatm.	0.9	16.3
	3		0.9	19.3
Condylus med	2	Amp	2.0	21.2
	1	Amp	L	27.3
	1	Preop rad + amp	L	22.3
	4		1.5	23.0
Tibia				
Condylus lat	1	Preop rad. + amp	L	17.2
	1	Preop rad + amp	0.7	14.7
	2		0.7	15.9
Condylus med	1	Amp	1.3	18.3
Metaphysis prox	3	Preop rad + amp	L	13.5
	1	Evac + part res + evac lymph nodes	L	27.9
	1	Evac + postop rad	1.9	13.0
	1	Rad treatm	0.3	8.0
	6		1.1	15.1
Diaphysis	1	Amp	6.2	68.8
	1	Amp	L	56.8
	1	Rad + cyt treatm	0.9	16.3
	3		3.7	47.3
Metaphysis dist	1	Amp	L	14.3
	2	Amp	1.4	16.2
	1	Preop rad + amp	L	12.9
	3	Preop rad + amp	1.2	14.5
	1	Evac + rad.	0.9	25.4
	8		1.2	16.0
Fibula				
Metaphysis prox	2	Amp	L	16.0
		Preop rad + amp	0.6	36.8
	1	Preop rad + loc res + amp	2.3	18.6
	1	Amp + postop rad	2.4	18.8
	1	Basic treatm	0.4	81.0
	7		1.2	32.0
Metaphysis dist	1	Amp	L	21.0
	1	Evac + amp	1.6	30.2
	2		1.8	25.6

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Humerus				
Metaphysis prox	1	Exartic	2 5	27 8
	3	Preop rad + amp	2 3	13 8
	1	Preop rad + exartic	0 7	64 1
	1	Evac + amp + postop rad	2 0	24 0
	2	Rad treatm	1 1	18 3
	1	Cyt treatm	0 6	5 3
	9		1 4	2[illegible]
Diaphysis	1	Extirp + postop rad	I	40 5
	1	Cyt treatm	0 9	83 3
	2		0 9	61 9
Metaphysis dist	1	Exartic + postop rad	0 3	53 1
	1	Rad treatm	4 9	36 5
	2		2 6	44 8
Radius				
Metaphysis dist	1	Preop rad + amp	L	21 1
Skull				
Maxilla	1	Radic res + postop rad	L	27 6
	1	Radic extirp + postop rad	L	6[illegible] 1
	1	Preop rad + radic extirp	L	29 8
	1	Preop rad + radic res	L	49 8
	4			42 3
Os parietable	1	Extirp + postop rad	3 8	25 8
Os temporale	1	Evac + radic extirp + postop rad	0 7	52 8
M[illegible]ndibula	1	Radic res + postop rad	0 6	28 2
	1	Preop rad + exartic	1 2	37 0
	1	Rad treatm	0 4	7 8
	1	Basic treatm	0 1	67 8
	4		0 6	35 2
Columnae vertebralis				
C VI	1	Extirp + postop rad	L	17 [illegible]
Th II	1	Rad treatm	1 3	34 0
L V	1	Extirp + postop rad	0 5	37 2
	4		0 8	31 4
Pelvis				
S II	2	Rad treatm	0 6	58 8
Ileum	1	Pad treatm	L	59 7
	1	Rad treatm	0 7	50 8

Location of tumour	Patients No	Treatment	Survival period years	Average age years
	1	Rad.cyt treatm	0 9	21 7
	1	Basic treatm.	0 1	21 5
	4		0 6	38 4
Pubis	1	Radic extirp	L	33 8
Ischii	2	Rad treatm	0 8	65 5
	1	Rad. + cyt.treatm.	0 8	77 2
	1	Basic treatm	9 0	5[illegible] 7
	4		2 8	65 2
Clavicula	1	Preop rad. + radic extirp	L	17 6
Sternum	1	Basic treatm	0 3	17 6
Scapula	1	Preop rad. + res part	0 5	31 8
	1	Evac + postop rad	0 8	37 1
	1	Rad.treatm.	3 6	58 5
	1	Cyt treatm	0 8	80 7
	1	Basic treatm	0 1	70 1
	5		1 1	55 6
Costa				
VII	1	Radic extirp + postop rad	0 3	53 4
IX	1	Preop rad. + radic extirp + postop rad	0 4	55 4
VI	1	Rad treatm	0 3	69 8
XII	1	Cyt treatm	0 1	80 0
	4		0 3	64 7

Table 3 Parosteal osteo-sarcoma location of tumour treatment average period of survival and average age (L = patient still alive survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur Diaphysis	1	Amp	L	38 7
Tibia Metaphysis dist	1	Radic res + bone transpl	L	23 0
Columnae vertebralis Th XI	1	Laminect + postop rad	L	[illegible]1 3
Mandibula	1	Preop rad + extirp + res part.	3 7	[illegible]1

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Humerus				
Metaphysis prox	1	Exartic	2 5	27 8
	3	Preop rad + amp	2 3	13 8
	1	Preop rad + exartic	0 7	64 1
	1	Evac + amp + postop rad	2 0	24 0
	2	Rad treatm	1 1	18 3
	1	Cyt treatm	0 6	5 3
	9		1 4	2? 2
Diaphysis	1	Extirp + postop rad	L	40 5
	1	Cyt treatm	0 9	83 3
	2		0 9	61 9
Metaphysis dist	1	Exartic + postop rad	0 3	53 1
	1	Rad treatm	4 9	36 5
	2		2 6	44 8
Radius				
Metaphysis dist	1	Preop rad + amp	L	21 1
Skull				
Maxilla	1	Radic res + postop rad	L	27 6
	1	Radic extirp + postop rad	L	62 1
	1	Preop rad + radic extirp	L	29 8
	1	Preop rad + radic res	L	49 8
	4			42 3
Os parietable	1	Extirp + postop rad	3 8	25 8
Os temporale	1	Evac + radic extirp + postop rad	0 7	52 8
Mandibula	1	Radic res + postop rad	0 6	28 2
	1	Preop rad + exartic	1 2	37 0
	1	Rad treatm	0 4	7 8
	1	Basic treatm	0 1	67 8
	4		0 6	35 2
Columnae vertebralis				
C VI	1	Extirp + postop rad	L	17 2
Th II	1	Rad treatm	1 3	34 0
L V	1	Extirp + postop rad	0 5	37 2
	4		0 8	31 4
Pelvis				
S II	2	Rad treatm	0 6	58 8
Ileum	1	Rad treatm	L	59 7
	1	Rad treatm	0 7	50 8

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Skull				
Basis	1	Basic treatm	0 1	58 5
Os ethmoideum	1	Extirp + postop rad	L	70 6
Columnae vertebralis				
Th IV	1	Extirp + postop rad + cyt.	L	40 2
L IV	1	Extirp + postop rad	0 7	26 1
	2		0 7	38 2
Pelvis				
Ileum	1	Hemipelvect	L	20 6
	1	Rad treatm	L	45 0
	4	Rad treatm	1 3	55 2
	1	Rad + cyt treatm	0 2	67 4
	1	Basic treatm	0 3	64 4
	8		1 0	52 3
Pubis	1	Rad treatm	L	55 0
	1	Rad treatm	0 7	60 8
	[illegible]		0 7	57 9
S I	2	Rad treatm	L	48 9
	1	Rad treatm	0 4	-4 0
	3		0 4	40 6
Sternum	1	Radic extirp	0 1	32 1
	1	Evac + extirp	L	33 1
	2		0 1	3- 6
Scapula	1	Part res	1 3	47 9
	1	Rad treatm	1 0	61 5
	2		1 2	54 7
Clavicula	1	Radic extirp	2 8	44 9
Costa				
IV	1	Radic extirp	L	-5.3
II	1	Radic res + Lobect pulm + postop rad	L	56 4
III	1	Part.res	1 9	40 2
VIII—IX		Rad treatm	4 2	50 4
	5		3 4	44 4

9 2 2 Cartilage forming tumours

Table 24 Primary chondro-sarcoma location of tumour treatment average period of survival and average age (L = patient still alive survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Clavifix	0 1	70 4
	1	*Hemipelvect*	*L*	*24 3*
	2		0 1	47 6
Trochanter	1	Amp	1 2	61 5
	1	Amp + cyt treatm	0 9	10 8
	1	Rad treatm	0 8	43 0
	3		1 1	46 2
Diaphysis	1	Rad treatm	1 8	76 3
	1	Rad + cyt treatm	0 6	15 3
	2		1 2	45 8
Metaphysis dist	1	Exartic	1 1	25 8
	1	Amp	0 5	36 8
	1	Amp + lymph nodes rad	0 3	6 5
	1	*Amp + postop rad*	1 0	15 4
	2	Amp + postop rad	4 4	16 8
	6		1 8	19 7
Condyl med	1	*Preop rad + amp*	L	45 8
Tibia				
Metaphysis prox	2	Amp	L	21 8
	2	Preop rad + amp	1 6	17 3
	1	Amp	2 0	18 1
	1	Amp + postop rad	2 0	63 6
	1	Rad + cyt treatm	0 5	10 0
	7		1 5	24 3
Humerus				
Collum	1	Rad treatm	1 9	49 0
Radius				
Diaphysis	1	Radic res + bone transpl	L	25 4
Metaphysis dist	1	Amp	*L*	*51 8*
Manus				
Metacarpus	1	Evac + exartic + postop rad	L	49 8
Phalanx	1	Amp	*L*	*58 3*

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Skull				
Basis	1	Basic treatm	0 1	58 5
Os ethmoideum	1	Extirp + postop rad	L	70 6
Columnae vertebralis				
Th IV	1	Extirp + postop rad + cyt.	L	40 2
L IV	1	Extirp + postop rad	0 7	26 1
	2		0 7	38 2
Pelvis				
Ileum	1	Hemipelvect.	L	20 6
	1	Rad treatm	L	45 0
	4	Rad treatm	1 3	55 2
	1	Rad + cyt treatm	0 2	67 4
	1	Basic treatm	0 3	64 4
	8		1 0	52 3
Pubis	1	Rad treatm	L	55 0
	1	Rad treatm	0 7	60 8
	2		0 7	57 9
S I	2	Rad treatm	L	48 9
	1	Rad treatm	0 4	24 0
	3		0 4	40 6
Sternum	1	Radic extirp	0 1	32 1
	1	Evac + extirp	L	33 1
	2		0 1	32 6
Scapula	1	Part res	1.3	47 9
	1	Rad treatm.	1 0	61 5
	2		1.2	54 7
Clavicula	1	Radic extirp	2 8	44 9
Costa				
IV	1	Radic extirp	L	25 3
II	1	Radic res + Lobect pulm. + postop rad	L	56 4
III	1	Part res	1 9	40 2
VIII—IX	2	Rad treatm	4 2	50 4
	5		3 4	44 4

Table 25 Secondary chondro sarcoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Preop rad + clavifix	L	4'4
Trochanter	1	Evac + bone transpl	L	7 5
	1	Part res + Postop rad + cyt	2 9	17 3
	2		2 9	2'4
Tibia				
Metaphysis prox	1	Evac + bone transpl	L	56 8
Humerus				
Caput	1	Preop rad + exartic	L	41 3
Metaphysis prox	1	Part res exostosis	L	11 4
Diaphysis	1	Evac	4 3	51 0
Manus				
Metacarpus	1	Evac + bone transpl	L	41 9
Phalanx	1	Amp	L	46 1
Columnae vertebralis				
Th VIII	1	Part res + postop rad	L	41 4
Clavicula	1	Radic res + postop rad	L	23 8
Pelvis				
Ileum	1	Rad treatm	0 9	71 5
Pubis	1	Rad treatm	3 3	60 7
Costa				
II	1	Radic extirp + postop rad + cyt	3 5	59 1
VI	1	Radic extirp + postop rad	L	58 1
	2		3 5	58 6

9.2.3 Giant cell tumours

Table 26 Malignant giant-cell tumours location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Preop rad + radic res (endoproth.)	L	43 6
Trochanter	1	Radic res + bone transpl	L	23 3
	1	Rad treatm	0 3	5.3
	1	Clavifix	1 6	53 4
	3		1 0	27 3
Diaphysis	1	Amp	1 8	63 3
	1	Evac + clavifix	0 7	72 2
	1	Clavifix + amp	4 8	66 3
	3		2 4	67 3
Condylus lat.	1	Evac + bone transpl	L	24 8
	1	Evac + postop rad	L	50 3
	2		L	37 6
Condylus med	1	Preop rad + amp	0 6	15 8
	1	Evac + postop rad	L	28 8
	2		0 6	22 3
Tibia				
Metaphysis prox	1	Amp	L	56 1
Diaphysis	1	Rad.treatm.	1 8	22 1
Metaphysis dist	1	Preop rad + evac	L	46 6
Fibula				
Metaphysis dist	1	Radic extirp	L	64 0
Radius				
Metaphysis dist	1	Res + amp	10 3	34 8
	1	Evac + bone transpl	L	30 2
			10.3	32 5
Columnae vertebralis				
Th V	1	Extirp + postop rad	L	35 5
Th XII	1	Extirp + postop.rad.	L	24 7
	2		L	30 1
Pelvis				
S II	1	Radic extirp	L	23 8
Ischii	1	Rad treatm.	0.3	54 7
Manus				
Metacarpus	1	Preop rad + evac + amp	L	14 4
Pedis				
Calcaneus	1	Extirp + postop rad	0 6	56 9
Phalanx	1	Amp	L	54 0
Mandibula	1	Rad.treatm	L	12.5

9 2 4 Bone marrow tumours

Table 27 Ewing s sarcoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Diaphysis	1	Preop rad + amp	L	24 [illegible]
Metaphysis dist	1	Hemipelvect	L	3[illegible] 2
Tibia				
Metaphysis prox	1	Amp + postop rad	2 4	14 3
Condylus lat	1	Preop rad + amp + cyt	1 1	11 7
Metaphysis dist	1	Amp + lymph nodes rad	1 3	36 1
	2	Rad + cyt treatm	1 8	12 4
	3		*1 6*	*16 9*
Humerus				
Caput	1	Amp + postop rad + lymph nodes oper	0 6	13 2
	1	Rad treatm	L	34 9
	2		0 6	24 1
Columnae vertebralis				
L I	1	*Rad treatm*	1 1	17 9
L III	1	Basic treatm	0 1	16 2
L IV	1	Cyt treatm	0 2	2 2
L V	1	Rad treatm	0 3	1 5
	4		0 4	9 5
Pelvis				
Ileum	1	Extirp + postop rad	1 8	15 2
	1	Excisio + postop rad + cyt	0 5	15 2
	1	Rad treatm	0 9	10 5
	3		1 1	13 6
Costa				
V	1	Rad treatm	0 3	39 0
VII	1	*Extirp + postop rad*	*0 8*	28 5
	2		*0 6*	*33 8*

Table 78 Reticulum-cell sarcoma location of tumour treatment, average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Trochanter	1	Rad. + cyt treatm.	L	59.2
Diaphysis	1	Basic treatm	0 3	14 4
Metaphysis dist.	1	Preop rad + amp	3 9	4 8
Condyli lat	1	Rad treatm	L	49.3
Columnae vertebralis				
Th IV	1	Laminect.	1 1	69.3
L II	1	Basic treatm	0 4	67 0
L IV	1	Rad. treatm.	3.2	72.2
L V	1	Rad. treatm	6 9	70 9
	4		2 7	69 9
Pelvis				
Ileum	1	Rad treatm	0 8	49 2
	1	Basic treatm.	0 1	38 0
	2		0 5	43.2
Pubis	1	Rad.treatm.	0 5	16 8
Ischii	1	Rad.treatm.	0.8	56 3
Sternum	1	Rad. + cyt.treatm.	0 4	71 1
Pedis				
Metatarsus	1	Rad treatm.	0 5	17 9

Table 29 Lympho-sarcoma Location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Clavifix + radic res + applic endoproth	0 7	68 1
Humerus				
Metaphysis dist	1	Rad + cyt treatm	1 5	42 8
Tibia				
Metaphysis prox	1	Amp	0 3	67 0
Columnae vertebralis				
Th XII	1	Laminect + postop rad	1 3	62 4
Pelvis				
Ileum	1	Rad treatm	0 3	10 1
Scapula	1	Rad + cyt treatm	0 3	31 1

Table 30 Solitary myeloma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Columnae vertebralis				
Th IX	1	Rad treatm	L	33 4
Th X	1	Laminect + postop rad	L	69 1
Th XII	1	Extirp + postop rad	L	35 5
L IV (IgG)	1	Rad + cyt treatm	0 4	64 4
L V (IgG)	1	Rad + cyt treatm	0 8	74 5
	5		0 6	55 6
Femur				
Diaphysis	1	Hormone treatment	L	22 1
Sternum	1	Rad treatment	0 2	79 1
Pelvis				
S II	1	Basic treatment	0 4	70 3
Costa				
IV	1	Rad treatment	L	32 6
VII	1	Extirp	0 1	50 7
	2		0 1	41 7

Table 31 Extra medullary plasma-cytoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Nose and hypo-pharynx	2	Rad treatm.	L	62 7
	2	Rad.treatm.	2 8	37.2
	1	Extirp	0 6	67.3
	1	Extirp + postop rad.	3 4	77.2
	1	Preop rad + extirp	L	54 1
	7		2.3	41 9
Maxilla (IgA)	1	Basic treatment	0.2	68.8
Orbit	1	Extirp + postop rad.	L	52.6
Reg inquinalis	1	Extirp	L	53 4

9.2.5 Vascular tumours

Table 32. Angio-sarcoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur Diaphy is	1	Rad treatm	0 4	68 8
Humerus Metaphysis prox.	1	Extirp	L	53 8
Skull Os parietale	1	Rad treatm	0.2	32 3
Columnae vertebralis Th II	1	Basic treatment	0 1	19 2

Table 33 Haemangio-pericytoma sarcoma location of tumour treatment, average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Tibia Metaphysis prox	1	Extirp	3 6	20 1
Scapula	1	Rad.treatm.	0.3	57.2

Table 29 Lympho-sarcoma Location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Clavifix + radic res + applic endoproth	0 7	68 1
Humerus				
Metaphysis dist	1	Rad + cyt treatm	1 5	42 8
Tibia				
Metaphysis prox	1	Amp	0 3	67 0
Columnae vertebralis				
Th XII	1	Laminect + postop rad	1 3	62 4
Pelvis				
Ileum	1	Rad treatm	0 3	10 1
Scapula	1	Rad + cyt treatm	0 3	31 1

Table 30 Solitary myeloma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Columnae vertebralis				
Th IX	1	Rad treatm	L	33 4
Th X	1	Laminect + postop rad	L	69 1
Th XII	1	Extirp + postop rad	L	35 5
L IV (IgG)	1	Rad + cyt treatm	0 4	64 4
L V (IgG)	1	Rad + cyt treatm	0 8	74 5
	5		0 6	55 6
Femur				
Diaphysis	1	Hormone treatment	L	22 1
Sternum	1	Rad treatment	0 2	79 1
Pelvis				
S II	1	Basic treatment	0 4	70 3
Costa				
IV	1	Rad treatment	L	32 6
VII	1	Extirp	0 1	50 7
	2		0 1	41 7

Table 31 Extra medullary plasma-cytoma location of tumour treatment, average period of survival and average age (L = patient still living survival over 6.5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Nose and hypo-pharynx	2	Rad treatm.	L	62.7
	2	Rad.treatm.	2.8	37.2
	1	Extirp	0.6	62.3
	1	Extirp + postop.rad	3.4	77.2
	1	Preop rad. + extirp	L	54.1
	7		2.3	41.9
Maxilla (IgA)	1	Basic treatment	0.2	68.8
Orbit	1	Extirp + postop.rad.	L	52.6
Reg inguinalis	1	Extirp	L	59.4

9.2.5 Vascular tumours

Table 32. Angio-sarcoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6.5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur Diaphysis	1	Rad.treatm.	0.4	68.8
Humerus Metaphysis prox	1	Extirp	L	55.8
Skull Os parietale	1	Rad.treatm.	0.2	3[illegible]3
Columnae vertebralis Th 11	1	Basic treatment	0.1	19.2

Table 33 Haemangio-pericytoma sarcoma location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Tibia Metaphysis prox.	1	Extirp	3.6	20.1
Scapula	1	Rad treatm.	0.3	52.2

Table 29 Lympho-sarcoma Location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Clavifix + radic res + applic endoproth	0 7	68 1
Humerus				
Metaphysis dist	1	Rad + cyt treatm	1 5	4[illegible] 8
Tibia				
Metaphysis prox	1	Amp	0 3	67 0
Columnae vertebralis				
Th XII	1	Laminect + postop rad	1 3	62 4
Pelvis				
Ileum	1	Rad treatm	0 3	10 1
Scapula	1	Rad + cyt treatm	0 3	31 1

Table 30 Solitary myeloma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Columnae vertebralis				
Th IX	1	Rad treatm	L	33 4
Th X	1	Laminect + postop rad	L	69 1
Th XII	1	Extirp + postop rad	L	35 5
L IV (IgG)	1	Rad + cyt treatm	0 4	64 4
L V (IgG)	1	Rad + cyt treatm	0 8	74 5
	5		0 6	55 6
Femur				
Diaphysis	1	Hormone treatment	L	2[illegible] 1
Sternum	1	Rad treatment	0 2	79 1
Pelvis				
S II	1	Basic treatment	0 4	70 3
Costa				
IV	1	Rad treatment	L	32 6
VII	1	Extirp	0 1	50 7
	2		0 1	41 7

Table 35 Primary malignant fibrous histio-cytoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Diaphysis	1	Extirp + postop rad.	4.3	[illegible]5 5
	1	Basic treatment	1 9	[illegible]5 3
	2		3 1	50 4
Tibia				
Metaphysis prox	1	Amp	1 3	1 3
Metaphysis dist	1	Preop rad + radic extirp	3 0	68 3
Humerus				
Metaphysis prox	1	Rad treatm.	L	15 [illegible]
	1	Rad + cyt treatm	0 4	16 0
	2		0 4	15 9
Fibula				
Metaphysis prox	1	Cyt treatm	0 3	55 2
Manus				
Metacarpus	1	Amp	0 7	65 1
Mandibula	1	Preop rad + extirp	L	44 7

9 2 6 Connective tissue tumours

Table 34 Fibro sarcoma location of tumour treatment average period of survival and average age (L = patient still living, survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Collum	1	Rad treatm	0 8	84 9
Diaphysis (Paget))	1	Preop rad + clavifix	0 3	66 4
Condylus med	1	Evac + postop rad	7 7	[illegible]5 2
Metaphysis dist	1	Extirp + postop rad	0 5	41 9
	1	Rad treatm	0 3	2 5
	1	Extirp + postop rad	2 2	71 0
	1	Cyt treatm	0 3	29 5
	4		0.8	36 2
Tibia				
Metaphysis prox	1	Preop rad + amp	1 3	18 3
Metaphysis dist	1	Amp + postop rad	3 0	37 0
Radius	1	Amp	0 4	77 8
Clavicula	1	Basic treatment	0 1	6[illegible] 0
Pelvis				
SI	1	Rad treatm	1 4	29 1
Costa				
XII	1	Extirp + postop rad	L	2 5
Mandibula	1	Evac + postop rad	L	61 2

Table 35 Primary malignant fibrous histio-cytoma location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Diaphysis	1	Extirp + postop rad	4 3	25 5
	1	Basic treatment	1 9	75 3
	2		3 1	50 4
Tibia				
Metaphysis prox	1	Amp	1.3	1 3
Metaphysis dist	1	Preop.rad + radic extirp	3 0	68 3
Humerus				
Metaphysis prox	1	Rad treatm.	L	15 7
	1	Rad + cyt treatm	0 4	16 0
	2		0 4	15 9
Fibula				
Metaphysis prox	1	Cyt treatm.	0 3	55 2
Manus				
Metacarpus	1	Amp	0 7	65 1
Mandibula	1	Preop rad + extirp	L	44 7

Table 36 NUD sarcoma location of tumour treatment average period of survival and average age (patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	*Survival* period years	Average age years
Femur				
Collum	1	Clavifix	1 5	15 5
Trochanter	1	Extirp + postop rad	2 3	27 4
Diaphysis	2	Basic treatment	0 1	6[illegible] 9
Tibia				
Metaphysis dist	1	Amp + postop rad	L	27 4
Humerus				
Metaphysis dist	1	Rad treatm	L	81 2
Columnae vertebralis				
Th I	1	Laminect	0 1	60 2
Th II	1	Rad treatm	1 7	40 3
	2		0 9	50 3
Pelvis				
Ileum	3	Rad treatm	0 8	71 9
Ischii	1	Basic treatm	0 1	67 2
Mandibula	1	Rad + cyt treatm	1 3	25 5
Sternum	1	Basic treatm	2 1	83 0
Clavicula	1	Rad treatm	1 0	62 3
Scapula	*1*	*Radic extirp*	1 2	52 1
	1	Rad treatm	0 9	48 6
	1	Rad + cyt treatm	0 5	33 8
	3		0 9	44 8

Table 37 Radiation sarcoma location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Condylus med	1	Amp	0 4	55 0
Humerus				
Metaphysis dist	1	Amp + postop rad	*0 1*	*52 6*

Table 38 Fibrolipo myxoma malignum location of tumour treatment average period of survival and average age (L = patient still living survival over 6 5 years)

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Diaphysis	1	Extirp + postop rad.	L	58 6

Table 39 Chondro-myxoma malignum location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Femur				
Trochanter	1	Evac + transpl oss	1.5	66 3

Table 40 Fibro-myxoma malignum location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Skull				
Os perietale	1	Extirp + postop rad	7 4	60 5

9 2 7 Other tumours

Table 41 Chordoma location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Skull				
Basis	1	Basic treatment	1.3	64 0
Columnae vertebralis				
L V	1	Laminect	0 6	59.3
Pelvis				
S 1	2	Extirp	8 9	54.2
	1	Basic treatment	0 4	54 5
	3		6 1	54.3

Table 42 Neuro-sarcoma location of tumour treatment average period of survival and average age

Location of tumour	Patients No	Treatment	Survival period years	Average age years
Columnae vertebralis				
L IV	1	Rad + cyt treatm	0 2	24 0

10 REFERENCES

Aakhus T Eide O Hoeg K & Poppe E Osteosarcoma A review of 41 cases Acta chir scand 126 520—530 1963

Aho A J Personal communications 19 9

Aho A J Einola S & Paasio J Role of strontium (⁸ Sr) scintigraphy in the clinical analysis of bone disease Ann chir gynae Fenn. 62 146—154 1973

Akahoshi Y Takeuchi S Chen C H Nishimato T Kikuike A Yomozawa H & Yamamuro T The results of surgical treatment combined with intra arterial infusion of anti cancer agents in osteosarcoma Clin orthop 120 103—110 1977

Arlen M Higinbotham N L Huvos A G Marcove R C Miller R T & Shah I Radiation induced sarcoma of bone Cancer 28 1087—1099 1971

Azar H A Zaino E C Pham T D & Yannopoulos K Nonsecretory plasma cell myeloma Am J Pathol 58 618—629 1972

Baird R J & Krause V W Ewing s tumours A review of 33 cases J Bone Jt Surg 43 A 136—140 1963

Baker S L Hyperplastic callus simulating sarcoma in two cases of fragilitas ossium J Path Bact 4 609—623 1967

Baldwin L W Thomas G Jr & Evans F B Primary bone tumors Survey of 137 cases Texas Medicine 63 64—74 1967

Banshali S K & Desai P B Ewing s sarcoma Observations of 107 cases J Bone Jt Surg 45 541—553 1963

Baumann F Operative problems of the lymphogenic metastazing sarcomas of the limbs In book Georg Shapcal Operative treatment of bone tumors Georg Thieme Verlag Stuttgart pp 119—123 1970

Beck A Zur Frage des Roentgensarkoms Zugleich ein Beitrag zur Pathogenese des Sarkoms Munchen Med Wschr 69 623—624 19 ?

Beck J C Wara W M Bovill E G & Phillips T L The role of radiation therapy in the treatment of osteosarcoma Radiology 120 163—165 1976

Bence Jones H On a new substance in the urine of a patient with mollities ossium Phil Tr Royal Soc London 55—6? 1848

Bethge J F J Die Ewingstumoren und Omoblastome des Konochens Ergebnisse der Chirurgie 39 327—4.5 1953

Biro L Einige Fragen der Diagnostik und Therapie der Plasmozytoms in der geriatrischen Praxis Z Alterforschung ?3 337—384 1971

Boyd J T Doll R Hill G B & Sissons H A Mortality from primary tumours of bone in England and Wales 1961—63 Britt J Prev Med 23 12—22 1969

Boyes J G Jr Primary reticulum cell sarcoma of the femur South. med J 67 335—339 1974

Burrows H J Wilson J N & Scales J T Excision of tumours of humerus and femur with restoration of by internal protheses J Bone Jt Surg 57 B 148—159 1975

Caceres E Zaharia M & Tantalean E Lymph node metastasis in osteogenic sarcoma Surgery 65 421—42? 1969

Cade S Osteogenic sarcoma A study based on 133 patients J Royal Coll Surg Edinburg 79—111 1955

Cahan, W G Woodard H Q Higinbotham N L Stewart F W & Coley E L Sarcoma arising in irriated bone Cancer 1 3—29 1948

Cambell W C Bone tumors J Tennesee Med Ass 27 379—385 1934

Cantell K Interferoni-tulevaisuuden aine Syopa-Cancer 6 6—9 1978

Carson C P Ackerman L V & Maltby J D Plasma cell myeloma Am J Path 25 849—888 1955

Catto M & Stevens J Liposarcoma of bone J Path Bact 86 248—253 1963

Cech O Pathological fractures in malignant tumors and their management *In book* Georg Shapcal Operative treatment of bone tumors *Georg Thieme Verlag pp 123—125* 1970

Cederlof S Hiertonn T & Salen E A follow up study of osteogenic sarcoma Acta orthop scand 30 107—114 1961

Christensen F C Bone tumours Am Surg 81 1074—1092 1925

Cohen D M Svien H J & Dahlin D C Long-term survival of patients with myeloma of the vertebral column J A M A 187 914—917 1964

Coley B L Higinbotham N L & Groesbeck, H P Primary reticulum cell sarcoma of bone Radiology 55 641—658 1950

Coley B L & Peterson R L Primary bone tumors in children Am J Surg 39 334—*341 1938*

Coley B L & Pool J L Factors influencing the prognosis in osteogenic sarcoma Ann Surg 112 1114—1128 1940

Compere C L Problems in the management of bone tumors Proc nat Canc Conf 381—383 1964

Compere E L Errors and safeguards in the treatment of bone tumors Internal Surgery 63 7—9 1978

Cook P L & Carbonne P P Myeloma of bone treated with sodium fluoride Clin Radiology 379—388 1968

Copeland M M Remarks by chairman Tumours of bone Proc nat Canc Conf 342—343 1964

Copeland M M Primary malignant tumours of bone Cancer 20 738—746 1967

Copeland M M Recent progress in chemo therapy and immunitherapy of sarcomas of bony origin both as primary and adjunctive therapy J Surg Oncol 9 2—14 1977

Copeland M M & Gesichter C F Chondroblastic tumors of bone benign and malig nant Am Surg 129 724—735 1949

Coventry M B & Dahlin D C Osteogenic sarcoma A critical analysis of 430 cases J Bone Jt 39 A 741—758 1957

Craver L F & Copeland M M Lymphosarcoma in bone Arch of Surg 809—824 1934

Cutler R L & Ederer F Maximum utilization of the life table method in analyzing survival J chron Dis 8 899 1958

Dahlin D C Malignant tumors primary in *bone Proc nat Canc Conf 359—380 1964*

Dahlin D C Bone tumors Charles C Thomas *Springfield-Illinois Second edition 1962*

Dahlin D C & Coventry M B Osteogenic sarcoma A study of six hundred cases J Bone Jt Surg 49 A 101—110 1967

Dahlin D C Coventry M B & Scanlon P W Ewing s sarcoma A critical study of 165 cases J Bone Jt Surg 43 A 185—197 1961

Dahlin D C & Henderson E D Chondrosarcoma A surgical and pathological problem J Bone Jt Surg 38 A 1025—1038 1956

Dahlin D C & Ivins J C Fibrosarcoma of bone Cancer 23 35—41 1969

Dahlin D C & MacCarty C Chordoma A study of fifty nine cases Cancer 5 1170—*1178 1952*

Davis L E & Drachman D B Myeloma neuropathy Succesful treatment of two patients and review of cases Arch Neurol 27 507—511 1972

Dawson E K Liposarcoma of bone J Path Bact 70 513—520 1955

Dedo R G Primary bone tumors in children J Florid med Ass 52 52—53 1971

Derian P S & Cook D E Primary malignant osseous and soft tissue tumors J Mississippi State med Ass 9 *219—226 1968*

Dissing I Sneppen O Heerfordt J & Schildt T Patient og laegeforsinkelse ved diagnosen af primaere maligne knogletumorer Vidsíiskap og praksis 283—1285 1977

Dockerty M B & Meyerding H W Adamantinom of the tibia J A M A 16 932—937 1942

Drivsholm A Myelomatose Munksgaard Copenhagen 1965

Dwinnel L A Dahlin D C & Chormley R K Parosteal *(juxtacortical) osteogenic* sarcoma J Bone Jt Surg *36 A 731—744* 1954

Ederer F Axtell L M & Cutler S J The

relative survival rate A statistical method ology Nat Canc Inst Monogr 6 101 1961

Esposito W J & Berne A S Polyostotic bone sarcoma associated with osteitis deformans Am J Roentgen Rad Ther 83 698—703 1960

Enelow A. J Psychososial rehabilitation for cancer patients Front Radiol Ther Onc 10 178—182 1975

Ewing J Diffuse endothelioma of bone J Bone Jt Surg 17—?4 192?

Ewing J Berckley lecture modern attitude toward traumatic cancer Arch Path. 19 690—?04 1935

Eyre Brook A L. & Price C H G Fibrosarcoma of bone J Bone

Falk S Alpert M Five year survival of patients with Ewing s sarcoma Surg Gynec Obstetrics 124 319—324 1967

Farrell C Mansfield G & Wallace J Thermography as an aid and in the diagnosis of tumours and detection of metastatic bone disease Britt J Radiology 41 897 1971

Feldman F & Lattes R. Primary malignant fibrous histiocytoma (Fibrous xathoma) of bone Skeletal Radiol 1 145—160 1977

Ferguson, A B Treatment of osteogenic sar coma J Bone Jt Surg ?? 916—9 8 1940

Fine G & Stout A P Osteogenic sarcoma of the extrasceletal soft tissue Cancer 9 10 7—1043 1956

Finkelstein J B Osteosarcoma of the jaw bones Rad Clinics North America 8 425—443 1967

Fischer H Trauma und Tumor Osterreich Zeitblatt Erforsch Bekampf Krebskr 26 *107—111 19 1*

Francis K C Higinbotham N I & Coley B L Primary reticulum cell sarcoma of bone Report of 44 cases Surg Gynaec Obstetr 99 143—146 1955

Francis K C Hutter R P V Phillips R K Eyerly R C & Schecter L Osteogenic sarcoma New Engl J Med 266 694—699 *196*

Francklin H S Pritchard M S & Ivins J C Foreguarter amputation Orthop Clinics North America 8 9?1—931 1977

Foster E A & Shambaugh E M Survival experience of patients with cancer of bone 1945—1959 Proc nat Canc Conf. 385—396 1964

Folsch, E Osteitis deformans Paget and sarcomatous degeneration Langenbecks Arch Klin. Chir 3? 359—369 1968

Garrington G E Scofield H H Cornyn, J & Hooker P Osteosarcoma of the jaws An analysis of 56 cases Cancer 20 377—391 1967

Geschichter C F & Copeland M. M. Parosteal osteoma of bone A new entity Ann Surg 133 ?90—807 1951

Gilmer W S & MacEven G P General (medullary) fibrosarcoma of bone J Bone Jt Surg 40 A 1?1—141 1958

Glenchur H Zinneman H H & Hall H W A review of fifty one cases of multiple myeloma A M A Arch. Int Med 103 173—183 1959

Gold H R Standart radiography arteriography xeroradiography and xeroarterio graphy in the evaluation of primary bone tumours Front Radiol Ther Onc 10 82—107 1975

Goldenberg R R Cambell C J & Bonfigs M. Giant cell tumors of bone An analysis of 218 cases J Bone Jt Surg 52 A 619—6?9 1970

Goldman R. L. Primary liposarcoma of bone Am J Clin. Path 42 503—508 1964

Gompels B M Votaw M L & Martel W Correlation of radiological manifestations of multiple myeloma with immunoglobulin abnormalities and prognosis Radiology 104 509—514 197?

Gosepath J Buchwald W & Reisner K Extramedullary plasmosytoma in the oral area HNO 17 338—342. 1969

Greenwald C M Mcaney T F & Hughes C R Chordoma — uncommon destructive lesion of cerebrospinal axis J A.M A. 163 1240—1244 *1957*

Grover S & Hardas U D Childhood malig nicies in Central Indie J nat Canc Inst 49 953—958 29 2

Grohn P & Heinonen, E Luusyovan laakehoito Syopa Cancer 6 13—14 1978

Guthert, H Ein malignes Neurinom des Knochens Zentralbl allg Path. 88 185—*189 19?2*

Hajdu S I & Melamed M R. Needle biobsy of primary *mal gnant* bone tumors Surg Gynec Obstetr 133 8?9—83? 1971

Hajdu S J Aspiration biopsy of primary malignant bone tumours Front Radiol Ther Onc 10 73—81 1975

Hatfield P M & Schulz M D Postradiation sarcoma including 5 cases after x-ray therapy of the brest carcinoma Radiology 96 593—602 1970

Harrington K D The role of surgery in the management of pathologic fractures Orthop Clinics North America 8 841—859 1977

Heilmann H P Strahlentherapie der Knochentumoren Deutsch Med Wochenschr 96 473—474 1971

Hellner H Knochengeschmacht und Unfall Arch orth Unfallchir 59 240—248 1966

Hellner H Osteomyelitis oder Sarkom? Bruns Beitr Klin Chir 213 129—151 1966

Henderson E D & Dahlin D C Chondrosarcoma of bone A study of two hundred and eighty eight cases J Bone Jt Surg 45 A 1450—1458 1963

Herenden R E The roentgen ray in the treatment of giant cell tumours Am J Roentgenol 12 117—125 1924

Herzog W Significance of lymphography for the general surgeons Bruns Beitr Klin Chir 219 193—198 1972

van der Heul R O & von Ronner J R Juxtacortical osteosarcoma diagnosis differential diagnosis treatment and an analysis of 80 cases J Bone Jt Surg 49 A 415—439 1967

Higinbotham N L & Coley B L Hemipelvectomy experiences in a review of 39 cases Cancer 9 1233—1238 1956

Hladik M Kolihova E & Tosowsky V Differentialcdiagnostische Schwierigkeiten bei malignen Knochentumoren in Kindesalter Radiologe 7 392—400 1967

Holmes E C & Morton D C Pulmonary resection for sarcoma metastases Orthop Clinics North America 8 805—810 1977

Holsti L R Lukander E Taskinen P J & Voutilainen A In book Syopataudit ja sa dehoito pp 232—236 Porvoo — Helsinki Juva WSOY 1977

Holsti L R & Holsti P Radiation therapy of osteosarcoma of the extremities XIII Internationale Concress of Radiology Madrid October 15—20 1973

Holsti L R & Patomaki L K F scanning of primary and metastatic bone tumours Ann med intern Fenn 56 131—135 1967

Honkomp J & Schomacher P H Angiographische Differential diagno e von Knochen tumoren Klinik und Forschung Chirurg 44 167—170 1973

Hoppe D & Mau S Zur Problematik malig ner Knochengewulste bei Erwach enen und Kindern und Ergebnisse der Behandlung Z artz Fortbild 62 13—17 1952

• Hutter R V B Worcester J N Jr Francis K C Foote F W Jr & Stewart F W Benign and malignant giant cell tumors of bone A clinicopathological analysis of the natural history of the disease Cancer 15 653—690 1972

• Huvos A G Higinbotham N I & Miller T R Bone sarcomas arising in fibrous dysplasia J Bone Jt Surg 54 A 1047—1056 1972

Huvos A G Rosen G & Marcove R C Primary osteogenic sarcoma Arch Path Lab Med 101 14—18 1977

Idenstrom K Cantell K Killander D Nilsson K Strander H & Willems J Interferon therapy in multiple myeloma Acta med scand 205 149—154 1979

Ivins J C Reticulum cell sarcoma Proc staff meeting Mayo Clinic 375—385 1963

Ivins J C Personal communication 1976

Jack G A & Vaeth J M Radiation therapy of primary reticulumcell sarcoma of bone in adults Front Radiol Ther Onc 10 167—169 1975

Jacobs P Radiological diagnosis of osteosarcoma Proc Roy Soc Med 69 543—546 1976

Jaffe H L Giant cell tumour (osteoclastoma) of bone its pathologic delimitation and the inherent clinical implications Moynihan Lecture delivered at the Royal College of Surgeons of England on 9th June 1953

Jaffe H L Tumour and tumours like conditions of the bones and joints Henry Kimpton London 1958

• Jaffe N Osteogenic sarcoma Clin orthop 120 95—102 1977

Jenkin R D Rider W P Sonley M J Ewing s sarcoma Princess Margaret Hospital Toronto 1960—1973 with particular references to total body radiation pp 265—277 In Sinks L F Golden J O Conflicts

in childhood cancer An evaluation of cur rent management New York — Lissabon 1975

Johnson J G Gilbert E Zimmerman B & Watne A. L. Gardner s syndroma Colon cancer and sarcoma J Surg Oncology 354—36? 1972

Kamrin R P Potanos J N & Tool J L. An evaluation of the diagnosis and treatment of chordoma J Neurol Neurosurg Psy chiatr 27 157—165 1964

Kittredge R D Arteriography in Ewings s tumor Radiology 97 609—610 1970

Klenerman L. Ochender B C & Towsend A C Osteosarcoma occurring in osteogenesis imperfecta J Bone Jt Surg 49 B 314—323 1967

Koskinen E V S Massive hyperplastic callus formation simulating osteogenic sarcoma in osteogenesis imperfecta Ann Chir gynaec Fenn 47 257—?71 1958

Koskinen E V S Heminelvectomy for malig nant tumours of bone Ann. chir gynaec Fenn 6 9—17 1967

Koskinen E V S Wide resection of primary bone and replacement with massive bone graft Clin orthop 134 302—319 1978

Koskinen E V S Personal communications 19 9

Koskinen E V S & Nieminen R Surgical treatment of metastatic pathological frac ture of major long bones Acta orthop scand 44 539—549 1973

Koskinen E V S Roukkula M. Ryoppy S & Vankka E The value on angiography in the diagnosis of bone and soft tissue tumours of the extremities Europ Ass Radiology Symph Ossium 40—44 1968

Koskinen E V S Salenius P & Alho A. Allogenic transplantation in low grade malignant bone tumors A new operative technique to avoid amputations Acta orthop scand. 50 129—138 19 9

Kotz, R Leber H Ramach W Areas H & Wolf A Erfahrurger mit der Durchfuhrung der hochdosierten Methotrexatebehandlung beim Osteosarkom Wiener klin Wochen schrift 14 474—479 1977

Kragh L. V Dahlin D C & *Brick J B* Osteogenic sarcoma of the jaws and facial bones Am. J Surg 96 496—525 1958

Krebs C Twenty five years experience in the treatment of osteosarcoma Acta Radiologica 58 369—384 196?

Krebs C & Olsen K Role of trauma in the development of malignant bone tumors Acta med scand 1 42—47 1963

Lacassagne A. & Vinzent R Sarcomes provoques cheg Lapins par L irradiation D Arbces A.Streptobacillus cavitae C R. de la Soc de biol 549—550 1978

Langenskiold F Om tumorer i de langa ror benen särskilt med hänsyn till diagnos och behandling Finska Lakarsallskapets Hand lingar L XXI 5 321—357 19 9

Leawell B B & Thoup O T Jr In book Fundamentals of clinical hematology W B Saunders Company Philadelphia and Lon don second edition pp 475—500 1966

Leskinen A Adlercreutz H Käariainen L. Renkonen O V Saris N E. & Uusitalo A Laboratoriotutkimusten vertailuarvoja *Sy* vapaino Espoo 1972

Lichtenstein L. Tumors of periosteal origin Cancer 8 1060—1069 1955

Lichtenstein L. Bone tumors The C V Mosby Company fourth edition Saint *Louis* 19??

Lindbom Å Soderberg G & Spjut H Osteosarcoma A review of 96 cases Acta Radiologica 56 1—19 1961

Lindbom Å Soderberg G & Spjut H Primary chondrosarcoma of bone Acta Radiologica 55 81—96 1961

Lissner J Elektronentherapie bei Sarkomen Med Klin 64 236 —?365 1969

Lochshin M D & Higgins T T Prognosis in osteogenic sarcoma Clin. orthop 58 85— 103 1963

Lodwick, G S Radiographic diagnosis and gradering of bone tumors with comments on computer evaluation. Proc nat canc *Conf* 369—380 1964

Lodwick G S Probalistic approach to the *diagnosis of* bone tumors Radiol Clinics North America 31 487—497 1965

Lodwick G S Haun, C L. Smith, W E Keller R. F & Robertson, E. D Computer diagnosis of primary bone tumors Radiology 80 273—275 1963

Lodwick G S & Reichert P J Computer assisted diagnosis of tumours and tumour like lesions of bone The limited Bayes concept. A preliminary raport Symp os

sium Jelliffe AMR Strickland B E & S Livingstone 1970

Lumb G & Prossor T M Plasma cell tumours J Bone Jt Surg 30 B 124—152 1948

MacDonald I & Budd J W Osteogenic sarcoma Surg Gynaec Obstetr 77 413—421 1943

Macintosh D J Price C H G & Jafferee G M Ewing s tumours J Bone Jt Surg 57 B 331—340 1975

MacKenzie A Court-Brown W M., Doll R & Sissons H A Mortality from primary tumours of bone in England and Wales Br Med J 1 1782—1790 1961

Mainzer F Minagi H & Steinbach L The variable manifestations of multiple enchondromatosis Radiology 99 377—388 1971

Marcove R C & Yang D-J Survival times after treatment of pathological fractures Cancer 20 2154—2158 1967

Marcove R C Chondrosarcoma Diagnosis and treatment Orthop Clinics North America 8 811—820 1977

Marie P Clunet J Raulet-Lapoink G Contribution a letude du development des tumeurs malignes sur les ulceres Roentgen Bull Assoc frenc p l etude du cancer 3 404—426 1910

Martin N S & Williamson J The role of surgery in the treatment of malignant tumours of the spine J Bone Jt Surg 52 B 227—237 1970

Martines-Maldonado M Yium J & Suki W N Renal complications in multiple myeloma Pathophysiology and some aspects of clinical management J Chronic Dis 24 221—237 1971

McCormack L J Dockerty M B & Chormley R K Ewing s sarcoma Cancer 5 85—99 1952

McCormack K R The role of nuclear medicine in primary bone tumours Front Radiol Ther Onc 10 108—114 1975

McKenna R J Schwinn C P Soong K Y & Higinbotham N L Osteogenic sarcoma arising in Paget s disease Cancer 17 42—65 1964

McLaughlin R E Wang G J & Ritchie W P Protractal survival in chondrosarcoma despite an usual metastasis that degressed spontaneously J Bone Jt Surg 61 A 137—139 1979

McLeod J J Dahlin D C & Ivins J C Fibrosarcoma of bone Am J Surg 94 437—437 1957

Mellstedt H, Bjorkholm M Johansson B Ahre A Holm G Strander H Interferon therapy in myelomatosis Lancet 1 245—248 1979

Meyers M H The role of limb and bone transplantation after resection or malignant disease Orthop Clinics North America 835—840 1977

Millburn L F O Grady L & Hendrickson F R Radical radiation therapy and total body irradiation in the treatment of Ewing s sarcoma Cancer 22 919—925 1968

Miller T R & Nicholson J T End results in reticulum cell sarcoma of bone treated by bacterial therapy alone or combined with surgery or radiotherapy (47 cases) or with concurrent infection (5 cases) Cancer 27 524—548 1971

Miller T R Hemipelvectomy in lower extremity tumors Ortop Clinics North America 903—919 1977

Mincey D L & Warnock M L Primary malignant lymohoma of mandible report of case J Oral Surg 32 221—224 1974

Mirdell E R Shah N R & Webster J H Postradiation sarcoma of bone and soft tissues Orthop Clinics North America 84 821—834 1977

Murphy W R & Ackerman L V Benign and malignant giant cell tumors of bone Cancer 9 317—339 1956

Mustakallio S Uber die malignen Riesenzell tumoren in Knochen Acta Duodecim Ser B 24 3—32 1937

Mustakallio S Primaaristen pahanlaatuisten luutuumorien rontgendiagnostiikka ja hoito Duodecim 62 1047—1062 1947

Nevanlinna H R Suomen vaestorakenne Kansanelakelaitoksen julkaisusarja Sarja A 9 120 1973

Nikkanen V Sytostaattihoidon perusteet Suomen Laakarilehti 18 1581—1583 1978

Nilsonne U Radical amputation for malignant tumours of extremities Acta chir scand 129 150—155 1965

Nordman E Per onal communication 1979

Nordman E Marjamaki H & Tommila O

The reliable of ^{99m}Tc pyrophosphate scin tigraphy in the diagnosis of bony metastases Ann clin research 9 31 31—34 1977
Oberkircher P E Miller W T & Arger P H Nonosseus preduction of plasma cell myeloma Radiology 104 515—520 19/2
Oberling C Les reticulosarcomes de la moelle oss use (sarcoma d Ewing) Bull de l assoc Frenc p l etude du Cancer 17 259—296 1928
O Hara J M Hutter R V P Foote F W Miller T & Woodard H Q An analysis of thirty patients surviving longer than ten years after treatment for osteogenic sar coma J Bone Jt Surg 50 A 335—354 1968
Oka M Intra arterial infusion of chemothera peutic agents in malignant bone tumors In book Georg Scapcal Operative treatment of bone tumors Georg Thieme Verlag Stuttgart pp 178—179 1970
Oldhoff J Treatment of recurrent osteosar coma In book Georg Shapcal Operative treatment of bone tumors Georg Thieme Verlag Stuttgart pp 133—135 1970
O Neal L W & Ackerman L V Chondrosar coma of bone Cancer 5 551—557 1952
Orava S Puranen J S Ala Ketola L Stress fractures caused by physical exercise Acta orthop scand 49 19—27 1978
Ott G & Wagner G Epidemiology of malig nant bone tumors Z Krebsforschung 89 ?31—?43 1977
Ottolenghi C E Massive osteo and osteo articular bone graft Technic and results of 5? cases Clin orthop 87 156—178 1972
Paavolainen P & Lyly T Chordoma in Fin land Acta orthop scand 47 46—51 1976
Paavolainen P & Sundell B Sakrokokkyge aalikordooma Duodecim 89 1239—1336 1973
Pack G T Major exarticulations for malig nant neoplasms of the extremities Inter scapulothoracic amputation hip joint disar ticulation and interilicabdominal amputa tion J Bone Jt Surg 38 ?49—26? 1956
Palva I Myeloman hoidon nykynakymat Duodecim 95 1053—1058 1979
Pankovich A M & Griem M L Plasmacell myeloma A thirty years follow up Radio logy 104 5 1—5 ? 1972
Parker J Jackson H Jr Primary reticulum cell sarcoma of bone Surg Gynaec Obstetr 68 45—53 1939
Parrish F F Allograft replacement of all or part of the end of long bone following ex cision of a tumor J Bone Jt Surg 55 A 1—5 1973
Phemister D B Chondrosarcoma of bone Surg Gynaec Obstetr 50 216—233 1930
Phemister D B Cancer of the bone and joint J A M A 136 545—554 1948
Phelan J T & Cabrera A Chondrosarcoma of bone Surg Gynaec Obstetr 119 42—46 1964
Phelan J T & Cabrera A Ewing s sarcoma Surg Gynaec Obstetr 118 795—800 1964
Phelan J T Treatment of pathological frac tures of the long bones from metastatic and primary cancer Cancer 21 1233—1238 1968
Phillips A J A mortality of primary tumors of bone in Canada Canadian Med Ass J 92 391—393 1965
Phillips R F & Higinbotham N L The cura bility of Ewing s endothelioma of bone in children J Pediatrics 80 391—397 1967
Phillips T L & Sheline G E Radiation therapy of malignant bone tumors Radio-logy 92 1537—1545 1969
Platt H Survival in bone sarcoma Acta orthop scand 3? 267—280 196?
Poole A G & Marcluetta F C Extrame-dullary plasmocytoma of the head and neck Cancer 2? 14—?1 1968
Poppe E Osteogenic sarcoma along what lines should it be treated Acta Radiologica 31 335—34 1949
Poprikov S Klinische Probleme der Karzino-menstehung auf Grund einer Osteomyelitis Bruns Beitr Klin Chir 216 537—544 1968
Prevo S B A clinical analysis of 205 of malignant bone tumors J Bone Jt Surg 32 A 298—306 1950
Price C H G The incidence of osteogenic sarcoma in South West England and its re lationship to Paget s disease of bone J Bone Jt Surg 44 B 36?—372 1962
Price C H G The prognosis of o teosarcoma An analytical study Britt J Radiology 39 181—188 1966
Price C H G Primary tumours of bone — their classification and incidence Britt J Radiology 41 897 1971
Price C H G & Goldie W Paget s sarcoma

of bone J Bone Jt Surg 51 B 205—224 1969

Price C H G Zauber K Salzer Kutschik M Salzer M Willebert H G Immenkamp M Groth P Matojowsky Z & Kevl W Osteosarcoma in children J Bone Jt Surg 57 B 341—345 1975

Pritchard D J Franklin H S Ivins J C Soule E H & Dahlin D C Fibrosarcoma of bone and soft tissues of the trunk and extremities Orthop Clinics North America 869—881 1977

Panke E Diagnostik und Therapie von Tumoren des Skeletalsystems Chirurg 39 188—191 1968

Rantakokko V Raajojen pehmytkudossarkoomat Turku 1978

Rao R S & Rao D N Prognostic significance in the regional lymph nodes in osteosarcoma J Surg Oncology 9 123—130 1977

Rauber-Kopsch Lehrbuch und Atlas der Anatomie des Menschen Georg Thieme Verlag p 101 1955

Reichmenn W Operative Therapie der primaren malignen Knochentumoren Roentgenbl 29 430—438 1976

Renner K Kasuistischer Beitrag zur Frage der Neuenstehung maligner Neoplasmen unter zytostatischen Therapie Strahlentherapie 142 308—311 1971

Richards A J Multiple myelomatosis from solitary myeloma of bone 13 years survival Proc Britt Soc Med 65 1019—1020 1972

Rissanen M & Holsti L R Sacrococcygeal chordomas and their treatment Radiol clin biol 36 153—155 1967

Robertson M A Harrington J S & Bradshaw E The cancern patterns in Africa of the transvaal Lo veld Cancer 20 738—746 1967

Rodman H J & Font R L Orbital involvement in multiple myeloma Arch Opthal 87 30—35 1968

von Ronnen J R & van Slooten E A Behandlung des Osteosarcoms des extremitaten Langenbecks Arch Chir 337 745—752 1974

Rosen G The development of an adjuvant chemotherapy program for the treatment of osteogenic sarcoma Front Radiol Ther Onc 10 115—133 1975

Ross F G M Osteogenic sarcoma Britt J Radiology 37 259—276 1964

Roukkula M Sarcoma Incidence and results of treatment Ann chir gynaec Fenn Suppl 91 1959

Sabanas A O Dahlin D C Childs O S & Ivins J C *Postradiation sarcoma of bone* Cancer 9 528—542 1956

Sack H Strahlenbehandlungen und Chemotherapie der primaren malignen Knochentumoren Rontgenbl 29 424—429 1976

Salenius P Luusvopa Syopa — Cancer 6 2—3 1978

Salenius P Personal communication *1979*

Santos L A & Murray J A Evaluation of giant cell tumor by computiried tomography Skeletal Radiol 2 205—219 1978

Sasse W Krupke H J & Hartung W Plasmocytome der Schilddruse Chirurg 44 52—54 1973

Scaglietti O & Calandriello B Ossifying parosteal sarcoma J Bone Jt Surg 44 A 635—647 1962

Schajowicz F Ackerman L V Sissons H A Sobin L H & Torloni H Histological typing of bone tumours World Health Organization 1972

Schajowicz F & Dergui J C Puncture biobsy in lesinos of the locomotor systems Cancer 21 531—548 1968

Schimer *H F Sayindis S Heger N Ristig* W Steckenmesser R & Kling G Die Stellung der Angiographie bei der Diagnostik von Knochentumoren Forschr Get Roentgenstrahl suppl 60—61 1972

Schwartz E E Fibrosarcoma following radiationtherapy J A M A 203 296—298 1968

Scanlon P W Split dose radiotherapy for radioresistant bone and soft tissue sarcoma Ten years experience Am J Rontgen Rad Ther & Nucl Med 114 544—552 1972

Sellors T H Treatment of isolated pulmonary metastases Britt Med J 2 253—256 1970

Sethi B S Clinic *A R W & Tuttle W M* Fibrous dysplasia of the rib with sarcoma tous change J Bone Jt Surg 44 A 183—188 1962

Sherman R S & Soong K Y Ewing s sarcoma Its roentgen classification and diagnosis Radiology 66 529—539 1956

Shoji H & Miller T R Primary reticulum

sarcoma of bone Cancer 28 1‿34—1244 1971

Sissons H A Personal communication 1977

Slootweg P J & Muller H Malignant fib rous histiocytoma of the maxilla Oral Surg 44 562—567 1977

Smith R J & Mankin H J Allograft repla cement of distal radius for giant cell tumor J Hand Surg 2 299—309 1977

Sneppen O Dissing I Heerfordt J & Schiold T Osteosarcoma of metatarsal bones Acta orth scand 49 2 0—?23 1978

Sneppen O F Johansson T Heerfordt J Dissing I & Petersen O Hemipelvectomy Postoperative rehabilitation assosed on the basis 41 cases Acta orth scand 49 175—1 9 19‚8

Solomon L Chondrosarcoma in hereditary multiple exostosis South Africa Med J 6 6 1—6‚6 1974

Sorvari T Personal communications 1976 19 9

Spanier S S Malignant fibrous histiocytoma of bone Orthopedics Clinics of North Amer rica 8 947—961 1977

Spanier S S & Enneking W F Primary malignant fibrous histiocytoma of bone Cancer 36 084—2098 197‿

Spjut H J & Luse S A Chordoma An electron microscopic study Cancer 17 643—656 1964

Steiner G C Postradiation sarcoma of bone Cancer 18 603—612 1965

Stevens G M Pugh D G & Dahlin D C Roentgenographic recognition and differen tation of parosteal osteogenic sarcoma Am J Roentgen 78 1—1 19‿7

Suomen virallinen tilasto VI A 134 Kuollei suus 1966—1970 Helsinki 1974

Tala P & Koikkalainen K Primary tumours of ribs and sternum Ann chir gynaec Fenn 56 3— 3? 1967

Tala P Koskinen E V S & Kuusmin, A Surgical treatment of pulmonary metas tasis of bone tumours Ann chir gynaec Fenn 56 437—443 1967

Tallberg T Personal communication 1976

Tallroth K Lymphatic dissemination of bone and soft tissue sarcomas Acta radiol Suppl 349 1976

Tanner H C Dahlin D C & Child D S Sarcoma complicating fibrous dysplasia O S O M & O P 14 83‚—846 1961

Teilbaum S L Twenty year's experience with intrinsic tumors of the bony thorax at a large institution J Thorac Cardio-vasc Surg 63 776—78 19 2

Teppo L Hakama M., Hakulinen T Lehto-nen M & Saxen E Cancer in Finland 1953—1970 Incidence mortality praeval lence Acta path microb scand Suppl. 25? 1973

Tikka U & Malmio K Clinical and radio-therapeutic aspects of reticulum cell sarco-ma Acta Radiologica 8 459—470 1969

Tong E C K & Rubenfeld S The Strontium 85 bone scan in myeloma Am J Roentgen 103 843—848 1968

Ullrich D P & Bucy P C Primary reticulum cell sarcoma of the skull Am J Roentgeno-logy 79 653—6‿7 1958

Virtama P Luukasvainten tietokonerontgen diagnostiikka Syovantorjunta 2 8—9 1973

Virtama P Nuoruusiänsairaus Syopa — Cancer 6 4—5 1978

Virtama P Katevuo K Makela P & Maki nen E O Computer aided diagnosis of bone tumors Acta rad. diagn. 20 70—74 1979

Voegeli E & Fuchs A Arteriography in bone tumours Britt J Radiology 49 407—415 19‚6

Voegeli E & Uehlinger E Arteriography in bone tumours Skeletal Radiology 1 3—14 19 6

Volkov N V Allotransplantation of joints J Bone Jt Surg 52 B 49—‿3 1970

Volkov N V Homotransplantation of bone in the operative treatment of bone tumors in children In book Georg Scaphall Ope rative treatment of bone tumors Georg Thieme Verlag Stuttgart pp 29—34 1970

Voutilainen A Their H & Kivivuori A Causal relationship between trauma and malignant tumours A medical and assur ance law study in the light of reported cases Ann chir gynaec Fenn 56 Suppl 152 1—49 1967

Wagner A & Schultis K Die Ablatio Inter thoracoscapularis als chirurgi che Therapie bei malignen Geschwulsten im Bereich der oberen Extremitat und der Schultergurtels Chirurg 92 ‚87—?95 1967

Waldenstrom J Patterns of plasmocytoma Schwiez med Eschreib 100 727—732 1970

Wang C C & Fleischli O J Primary reticulum cell sarcoma of bone Cancer 22 994—998 1968

Wang C C Treatment of primary reticulum cell sarcoma of bone by irritation New Engl J Med 278 1331—1332 1968

Wang C C & Milford Ewing s sarcoma A study of fifty cases treated in the Massaschusett s General Hospital 1930—1958 New Engl J Med 248 571—576 1953

Wang C C & Schulz M D Ewing s sarcoma J Med 24 571—576 1953

Wasastjarna C Multippeli myelooma Duodecim 90 751—764 1974

Webber W B & Wienke E C Malignant fibrous histiocytoma of the mandible Plastic and Recontruct Surg 629—634, 1977

Weiland A J & Rodin K D Microvascular anastomoses for bone grafts in the treatment of massive defects in bone J Bone Jt Surg 61 A 98—104 1979

Welte W & Braune M Knochentumoren im Kindesalter Monatschr Kinderheilk 122 65—68 1974

Williams R R Dahlin D C & Ghrosley R K Giant cell tumor of bone Cancer 7 764—773 1964

Wilson J N The treatment of pathological fractures with spesial reference to the use of major prosthetic replacement of bone Ital J Orthop Traumat Suppl 1 1975

Wiltshaw E The natural history of extrame dullary plasmocytom and its relation to solitary myeloma of bone and myelomatosis Medicine 55 217—238 1976

Wolfel D A & Cortes P R Parosteal osteosarcoma Am J Roentgen 105 142—146 1969

Woodard H G & Coley B L The correlation of tissue dose and clinical responce in irridiation of bone tumours and normal bone Am J Roentgen 57 464—471 1947

Wu K K & Kelly A P Periostal (juxtacortical) chondrosarcoma Report of a case occuring in the hand J Hand Surg 2 314—315 1977

Yaghmai I In book Angiography of bone and soft tissue lesions Springer Verlag Berlin & New York 1979

Yaghmai I A Zia A Z Shariali S & Afshari H Value of arteriography in the diagnosis of benign and malignant bone lesions Cancer 29 1134—1147 1971

Yamamoto I Bone tumours Human Pathol 2 531—532 1971

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INTRODUCTION

The pathogenesis of osteoarthritis is still not known In general the disease is regarded as a result of degeneration a wear and tear phenomenon as well as a disorder of advanced age

Over the years innumerable studies have been concerned with attempts to elucidate this disorder Most investigators have been engaged in the study of articular cartilage and alterations in this tissue usually are considered the primary stage of osteoarthritis Others have entertained the idea that basically osteoarthritis is a vascular disease and that the initial changes are to be found in the subchondral bone However the cause of these changes is still obscure Although general factors may contribute to certain forms of osteoarthritis it is generally agreed that local factors are of more importance These may vary from joint to joint

The present paper deals with the pathomechanism of primary osteoarthritis of the hip joint It has been our intention to analyse the results of a series of investigations on changes in the synovial membrane the synovial fluid articular cartilage and the sub- and juxtachondral bone and bone marrow Our choice of methods depended on the resources of our laboratories and the subjects of investigation upon a working hypothesis developed during the years 1970-1975 (Fig 1) Thus this work is not intended as a systematic treatise on the pathogenesis of osteoarthritis Instead it is first and foremost a synthesis of our findings a search for internal correlation and an attempt to determine which of the many gaps in our knowledge are of most importance for further studies

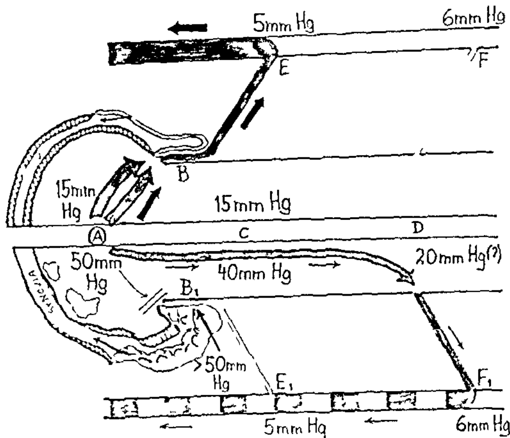


Fig 1 The data known from intraosseous pressure measurements and phlebography in 1975 and the basis for the studies represented in this paper

THE SYNOVIAL MEMBRANE

The histopathological features of osteoarthritic synovium have been considered non specific (Roy 1967) and controversy about the role of the synovial membrane has persisted Though many are of the opinion that changes in the synovium are secondary to cartilage destruction and result from displacement of joint detritus into the synovium (Lloyd Roberts 1953) it is a clinical experience that synovitis is a very early and consistent feature also in primary osteoarthritis

In contrast to rheumatoid synovium the changes in the synovial membrane of osteoarthritic joints described in the literature are not very detailed Proliferation of lining cells hypertrophy of villi and absence of or only slight inflammatory changes have been mentioned (Wilkinson & Jones 1963 Roy 1967 Huth et al 1973) and vascular changes of the same pattern as observed in rheumatoid arthritis were described by Goldie (1970)

INTRODUCTION

The pathogenesis of osteoarthritis is still not known In general the disease is regarded as a result of degeneration a wear and tear phenomenon as well as a disorder of advanced age

Over the years innumerable studies have been concerned with attempts to elucidate this disorder Most investigators have been engaged in the study of articular cartilage and alterations in this tissue usually are considered the primary stage of osteoarthritis Others have entertained the idea that basically osteoarthritis is a vascular disease and that the initial changes are to be found in the subchondral bone However the cause of these changes is still obscure Although general factors may contribute to certain forms of osteoarthritis, it is generally agreed that local factors are of more importance These may vary from joint to joint

The present paper deals with the pathomechanism of primary osteoarthritis of the hip joint It has been our intention to analyse the results of a series of investigations on changes in the synovial membrane the synovial fluid articular cartilage and the sub and juxtachondral bone and bone marrow Our choice of methods depended on the resources of our laboratories and the subjects of investigation upon a working hypothesis developed during the years 1970 1975 (Fig 1) Thus this work is not intended as a systematic treatise on the pathogenesis of osteoarthritis Instead it is first and foremost a synthesis of our findings a search for internal correlation and an attempt to determine which of the many gaps in our knowledge are of most importance for further studies

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Fig 3 A *Synovial membrane from a man aged 63 with coxarthrosis Marked venous stasis Haematoxylin/eosin magnification x 25*

B *Same as A Note interstitial oedema Magnification x 100*

C *Synovial membrane from a woman aged 64 with fracture of the femoral neck Haematoxylin/eosin magnification x 25*

Compared with the control group the biopsies from both osteoarthritic and rheumatoid arthritic hip joints showed characteristic vascular changes The venules and capillaries were dilated and packed with erythrocytes (Fig 3 A B and C) hypertrophy of the arterioles was often present and an increased permeability of the capillary wall was suggested by the presence of interstitial oedema free erythrocytes and haemosiderine deposits in the interstitial tissue (proliferative type) In almost half the cases of osteoarthritis there was an increased amount of fibrosis (fibrous type)

Electron microscopy Electron microscopy confirmed the changes seen by light microscopy Free erythrocytes were often seen in the interstitial tissue or penetrating the capillary wall which was intact and of normal appearance This is in accordance with the observations by Dryll et al (1977) who have shown an increased transcapillary migration of circulating blood cells but a normal structure of the capillary wall

Histochemical Investigations

Compared with rheumatoid arthritis only slightly increased levels of acid and alkaline hydrolase activity have been demonstrated by biochemical methods (Kar et al 1976) In order to investigate whether this increased activity is consistent with the morphological changes of the synovial membrane seen in our histological studies a histochemical analysis of alkaline and acid phosphatase in osteoarthritic synovium from human hip joints was carried out (Reimann & Christensen 1979)

Frozen sections of synovial biopsies from 12 osteoarthritic hip joints were studied Biopsy samples from six patients with fracture of the femoral neck were used as control together with two biopsies from the knee joints of young patients with torn menisci The *enzymo-histochemical* analyses were performed using Burstone s (1959) method for demonstration of non-specific alkaline phosphatase

Recently a grading system of the histological criteria for inflammation has been proposed (Salvati et al 1977) and an increased enzyme level has been demonstrated biochemically (Kar et al 1976 Salvati et al 1977)

Own Investigations

Electron and light microscopic study of the synovial membrane

To explore the representative features in osteoarthritic synovium we performed an electron and light microscopic study of the synovial membrane from human hip joints The material consisted of biopsies from 24 osteoarthritic hip joints and for comparison biopsies from twelve patients with rheumatoid arthritis Biopsies from eight patients with fracture of the femoral neck were used as controls (Arnoldi et al in press 1979 c)

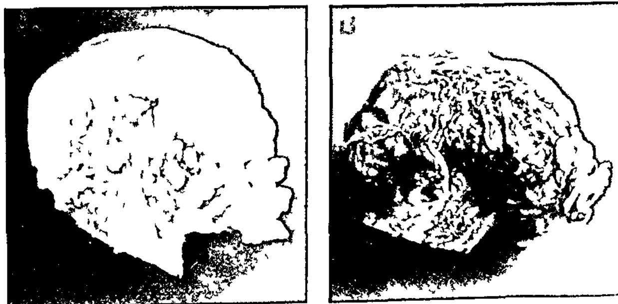


Fig 2 A *Femoral head from a woman aged 71 with coxarthrosis and proliferative synovitis*
B *Femoral head from a man aged 71 with coxarthrosis and fibrous synovitis*

Gross inspection of the synovial membrane in coxarthrosis Two relatively distinct types of synovitis were observed in patients with coxarthrosis an early proliferative type and a late fibrous type The proliferative type was characterized by increase of synovial fluid in the joint and bulky volume of the synovium the oedematous tissue often having the appearance of a juicy bunch of grapes (Fig 2 A) In the fibrous type most of these grapelike protuberances had disappeared and been replaced by stringy bands of fibrous scar tissue (Fig 2 B) In the fibrous type the hip joint usually contained very little fluid

Light microscopy The light microscopic examinations revealed that the osteoarthritic synovium as estimated by the grading system introduced by Salvati et al (1977) only showed slight to moderate degrees of inflammation in contrast to the rheumatoid synovium which was characterized by pronounced focal as well as diffuse inflammation

edematous fluid and to haemosiderine deposits in the interstitial tissue The subsequent development f fibrosis and scarry transformation of the synovial membrane is probably the long term reaction of nesenchymal tissue to these changes This conception is supported by the knowledge of a similar rocess which develops in the skin and subcutaneous tissues of the ankle region in patients with hronic venous insufficiency In these patients a purely mechanical disorder of the venous pump of the alf leads to an ambulatory hypertension in the veins and venules of the ankle region with impeded apillary flow (Arnoldi 1966) The early reaction is oedema and increased capillary permeability to roteins and erythrocytes (Zweifach 1940) Large deposits of haemosiderine in the interstitial tissue give rise to the well known brown discolouration in the lower leg that is so common in these patients Haemosiderine is a strong tissue irritant and causes an inflammatory reaction in the subcutis which undergoes a scarry transformation The previously swollen leg shrinks The scarry tissue is palpable as induration" The final stage of this degenerative process is the chronic venous leg ulcer (Haxthausen 1936 Arnoldi & Linderholm 1968 Arnoldi 1976)

Any process that results in an elevation of intraarticular pressure could probably initiate the changes observed in the osteoarthritic synovium Examination of pressures in the extraarticular veins of the hip region (Arnoldi et al 1979 a) indicates that elevation of intraarticular pressure by as little as 5 10 mmHg is sufficient to impede the flow through the synovial veins (see later) The process may begin as an inflammatory reaction caused e g by trauma or mechanical dysfunction of the joint with increased production of synovial fluid Due to the rigid character of the fibrous capsule any increase in volume is accompanied by an increased intraarticular pressure that in its turn will block the venous blood flow and add the effect of venous stasis to the inflammatory reaction (Arnoldi et al 1979 a) The subsequent effect of further increased capillary permeability could result in a self perpetuating process

THE SYNOVIAL FLUID

As synovial fluid is a dialysate of blood plasma to which hyaluronate – synthesized by synovial lining cells – is added the changes in the synovial membrane in coxarthrosis described above should be reflected in the composition of the synovial fluid As shown by Lund-Olesen (1970) there seems to be a decreased oxygen tension in synovial fluid from osteoarthritic joints but to a lesser degree than in rheumatoid synovia He also observed a significant correlation between PO_2 and pH and between PO_2 and PCO_2 It is known that the protein concentration in osteoarthritic synovia is slightly increased (Ropes & Bauer 1953) and that there is an abnormal protein pattern (Kushner & Sommerville 1971 Pruzanski et al 1973 Willumsen & Friis 1975) Further it has been shown that the passage of protein through the synovial vascular walls is affected by molecular size and by presence of inflammation (Kushner & Sommerville 1971)

Own investigations

Protein analysis

To elucidate the permeability of the osteoarthritic synovium to plasma proteins of varying molecular size we performed an analysis of the ratios of synovial fluid concentration to serum concentration (SF/S) for four non immunoglobulin proteins from osteoarthritic and normal hip joints We also

activity and Barka & Anderson s (1963) method for demonstration of acid phosphatase activity For semiquantitative estimation of the enzyme activity the initial time was used as described by Hopsy & Glenner (1965)

The enzyme levels were significantly increased in the osteoarthritic synovium compared with the controls The significance of increased alkaline phosphatase acticity is not yet clear However the alkaline phosphatase was found located in fibroblasts below the lining cells and in capillaries and precapillary arterioles Thus, the increased activity is presumably consistent with the increased vascularity and fibrosis found by histological examinations

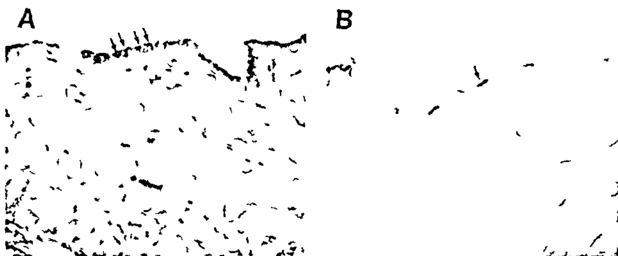


Fig 4 A *Frozen section from osteoarthritic synovium The acid phosphatase reaction is seen in superficial lining cells (arrows) Magnification x 100*
B *Frozen section from control synovium The acid phosphatase reaction is seen in a few of the superficial lining cells Magnification x 100*

It is generally agreed that increased acid phosphatase activity is involved in the process leading to cartilage damage Other lysosomal enzymes presumably play a greater role but acid phosphatase is a good marker enzyme for lysosomal enzymes As acid phosphatase was found located in the lining cells (Fig 4 A and B) probably mainly in the A type which is rich in lysosomes the proliferation of the lining cells – a general histological finding in various types of synovitis – is probably a contributory factor to the increased activity

The histochemical changes observed in the synovium thus seem to correlate with the histological findings

Discussion

In patients with coxarthrosis the histological examination of the synovium in proliferative synovitis shows a picture that is dominated by venous stasis and capillary dilation The few and scattered inflammatory cells could well be explained as a reaction to increased protein content in the

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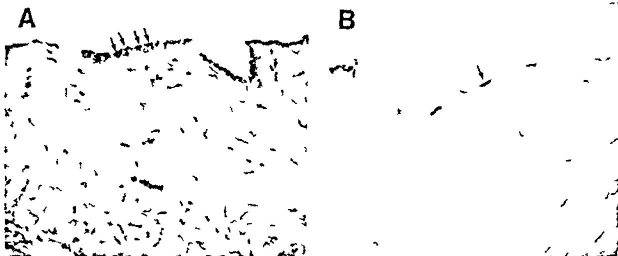


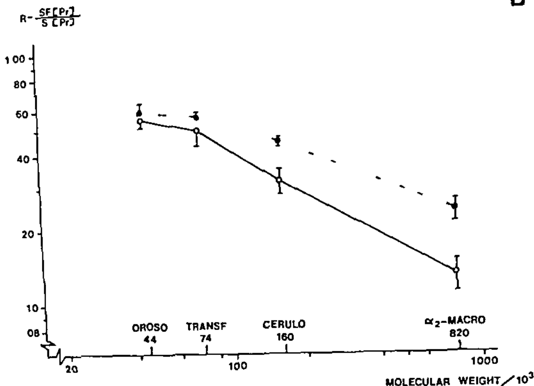
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B *Intraindividual values from eight patients*

Our results showed that the variations in SF/S ratios from the normal hip joints were insignificant Furthermore the analyses showed the same pattern in an intraindividual study as when all the samples from the osteoarthritic joints were compared with the normal samples (Fig 5 A and B)

The analyses showed a relationship between SF/S and molecular weight as described previously (Nettelbladt & Sundblad 1959 Kushner & Sommerville 1971 Pruzanski et al 1973 Willumsen & Friis 1975) The ratios were higher for osteoarthritic synovia than for normal and the difference increased with increasing molecular weight and was highly significant for the largest molecules ($p < 0\ 001$) An almost inverse linear relationship was observed between SF/S ratios of the proteins and their molecular weight (Fig 5 A and B) These findings indicate an increased capillary permeability in the synovial membrane

Relationship between protein ratios and inflammation in synovial fluid in different joint diseases has been described by Kushner & Sommerville (1971) They found that increasing degrees of inflammation corresponded to higher SF/S ratios with greatest increases in large molecules Patients with osteoarthritis showed least evidence of inflammation

In this series the degree of inflammation was estimated by histological examination of the synovial membrane It was impossible to correlate the degree of inflammation in the synovium with the protein ratios owing to the very slight degree of inflammation observed in the osteoarthritic synovium

investigated whether these changes were correlated to the histological features in the synovial membranes in patients with coxarthrosis (Reimann et al in press 1979)

The synovial fluid was obtained at the time of replacement surgery from 46 patients with unilateral coxarthrosis Blood samples from a vein on the forearm were taken simultaneously Criteria for unilateral coxarthrosis were that the patients showed a radiologically normal contralateral hip without clinical symptoms and that there was no accentuation of the normal uptake pattern at osteoscintigraphy with ^{99m}Tc polyphosphate (Heerfordt et al 1976)

The simultaneously aspirated synovial fluids and sera were analysed with electro immunoassay as described by Laurell (1965) The proteins studied were orosomucoid molecular weight 44 000 transferrin (74 000) ceruloplasmin (160 000) and α_2 macroglobulin (820 000) Recently it has been shown that Stoke s radius which is a function of molecular weight volume and shape is a more appropriate expression of protein size than molecular weight alone (Burnett et al 1975) However the size of Stoke s radius for the four proteins investigated roughly correlates with the molecular weight (Burnett et al 1976 Renkin 1977) Further local synthesis or destruction in the synovial membrane of these proteins has not been shown (Kushner & Sommerville 1971) The SF/S ratio thus reflects the synovial permeability for the single protein

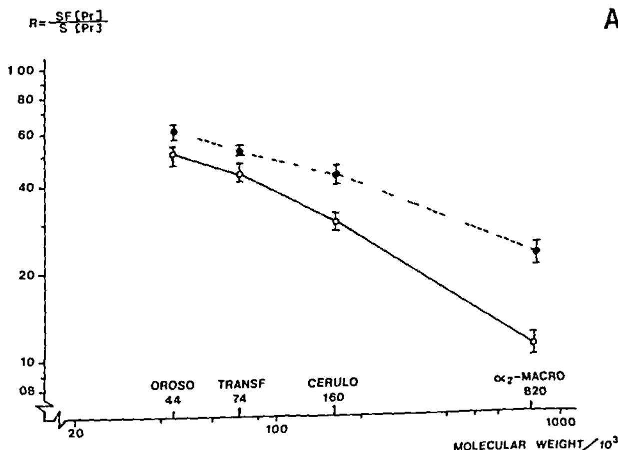
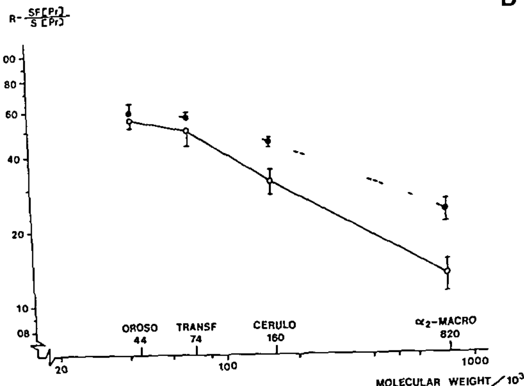


Fig 5 A Log/log plot of SF/S ratio and molecular weight from hip joints with osteoarthritis (black circles) and from normal hip joints (open circles) Ratio determined for the four non immunoglobulin proteins represent the mean ∓ SD of 29 and 23 samples respectively



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As previously described it is possible to distinguish between a proliferative and a fibrous type of synovitis in coxarthrosis By comparing the ratios of the four proteins in these two types it was found that patients with proliferative synovitis showed higher SF/S ratios than those with fibrous synovitis The difference was significant for α_2-macroglobulin ($p<0.01$) Thus the abnormal protein pattern in osteoarthritic synovia reflects an increased capillary permeability in the synovial membrane and it seems to correlate with the histological features

Discussion

Swelling and pain are regular features in all inflammatory joint disease typified by rheumatoid arthritis It is also a common symptom after trauma or overloading more easily noticed e g in the knee than in the hip joint The patient with primary coxarthrosis is generally in his late fifties or sixties when he is seen by the orthopaedic surgeon However a careful history will often reveal periods of intermittent pain in the hip region combined with limping during the years preceding the state of manifest osteoarthritis During this period when the X rays are normal the patients are rarely seen by the orthopaedic surgeon but by their family physician or a rheumatologist The treatment – if any – is conservative mainly consisting of rest occasionally combined with physical treatment of various kinds and during the recent decade medication with one or several of the non steroid antiphlogistica This conservative regimen is often effective but in some cases the symptoms return periodically until the diagnosis osteoarthritis becomes obvious This conservative treatment is essentially a treatment of synovitis

Thus there are clinical indications that even primary coxarthrosis does not appear suddenly and without warning sometime after the fifty fifth birthday The history is more likely to suggest that clinical osteoarthritis is the final stage of a fairly long lasting joint disorder Our clinical experience suggests that many attacks of synovitis disappear without doing permanent damage to the joint In certain cases the attack leads to manifest coxarthrosis within a short period of time but in most cases of primary coxarthrosis the synovitic episodes stretch over a number of years before the typical roentgen changes become visible

Inflammation joint effusion and subsequent stasis result in a vascular derangement in the synovial membrane Increased capillary permeability is followed by a change in the protein pattern and the amount of protein in the synovia One of the functions of the synovial fluid is joint lubrication As shown by Reimann et al (1975) and Reimann (1976) boundary lubrication is reduced in rheumatoid arthritis and osteoarthritis It seems probable that this deterioration is due to the change in the protein pattern of the synovial fluid

The increased production of acid phosphatase and lysosomes known to be of importance for the degenerative changes of articular cartilage and the reduction of oxygen in the synovial fluid (Lund Olesen 1970) are of special importance as the synovia is the vehicle for supply of oxygen and nutrition to the cartilage Further decreased oxygen tension is of significance for release of lysosomal enzymes (de Duve 1964)

The mechanical effect of synovitic joint effusion is discussed on p 21

VASCULAR CHANGES IN JUXTAARTICULAR BONE MARROW

The fact that degenerative changes usually are caused by a failure in the supply of oxygen and nutrition to the tissues involved focussed attention on the state of the arterial supply to the joint in many early studies on osteoarthritis As late as the middle of this century many authors were of the opinion that osteoarthritis of the hip was accompanied or preceded by a state of ischaemia of sub- and juxtachondral bone (Wollenberg 1909 Goldhaft et al 1930 Phemister 1940 Pridie 1952) This conception was challenged by Harrison et al (1953) By means of injection studies on cadavers they found a hyperplasia of the intraosseous arteries in the femoral head and on the basis of this observation they assumed that the arterial inflow to the femoral head was increased instead of reduced in coxarthrosis The same authors also found signs of venous stasis in the bone marrow

In the years following this study investigations by means of intraosseous phlebography provided evidence of disturbed venous outflow from the femoral head and neck in patients with coxarthrosis and from the distal part of the femur in patients with gonarthrosis (Ménel et al 1955 Hulth 1959 Helal 1962 Wardle 1964 Phillips 1966) and increased intramedullary pressure in juxtachondral bone marrow (Arlet et al 1968)

Own investigations

Intraosseous phlebography and measurements of intraosseous pressure

Coxarthrosis In a series of 15 patients with unilateral painful primary osteoarthritis of the hip joint Arnoldi et al (1972 a) measured the pressure in the bone marrow of both femoral necks and the femoral vein These examinations were followed by bilateral serial intraosseous phlebography of the proximal part of the femur

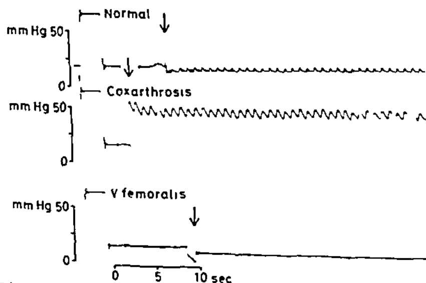


Fig 6 Bilateral measurements of intraosseous pressure in the femoral neck with simultaneous recording of femoral vein pressure Patient with unilateral coxarthrosis

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Thus, there are clinical indications that even primary coxarthrosis does not appear suddenly and without warning sometime after the fifty-fifth birthday. The history is more likely to suggest that clinical osteoarthritis is the final stage of a fairly long-lasting joint disorder. Our clinical experience suggests that many attacks of synovitis disappear without doing permanent damage to the joint. In certain cases the attack leads to manifest coxarthrosis within a short period of time, but in most cases of primary coxarthrosis the synovitic episodes stretch over a number of years before the typical roentgen changes become visible.

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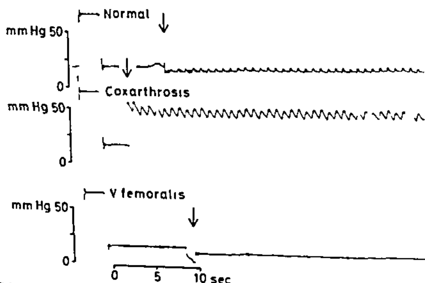


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Swelling and pain are regular features in all inflammatory joint disease typified by rheumatoid arthritis It is also a common symptom after trauma or overloading more easily noticed e g in the knee than in the hip joint The patient with primary coxarthrosis is generally in his late fifties or sixties when he is seen by the orthopaedic surgeon However a careful history will often reveal periods of intermittent pain in the hip region combined with limping during the years preceding the state of manifest osteoarthritis During this period when the X rays are normal the patients are rarely seen by the orthopaedic surgeon but by their family physician or a rheumatologist The treatment – if any – is conservative mainly consisting of rest occasionally combined with physical treatment of various kinds and during the recent decade medication with one or several of the non steroid antiphlogistica This conservative regimen is often effective but in some cases the symptoms return periodically until the diagnosis osteoarthritis becomes obvious This conservative treatment is essentially a treatment of synovitis

Thus there are clinical indications that even primary coxarthrosis does not appear suddenly and without warning sometime after the fifty fifth birthday The history is more likely to suggest that clinical osteoarthritis is the final stage of a fairly long lasting joint disorder Our clinical experience suggests that many attacks of synovitis disappear without doing permanent damage to the joint In certain cases the attack leads to manifest coxarthrosis within a short period of time but in most cases of primary coxarthrosis the synovitic episodes stretch over a number of years before the typical roentgen changes become visible

Inflammation joint effusion and subsequent stasis result in a vascular derangement in the synovial membrane Increased capillary permeability is followed by a change in the protein pattern and the amount of protein in the synovia One of the functions of the synovial fluid is joint lubrication As shown by Reimann et al (1975) and Reimann (1976) boundary lubrication is reduced in rheumatoid arthritis and osteoarthritis It seems probable that this deterioration is due to the change in the protein pattern of the synovial fluid

The increased production of acid phosphatase and lysosomes known to be of importance for the degenerative changes of articular cartilage and the reduction of oxygen in the synovial fluid (Lund Olesen 1970) are of special importance as the synovia is the vehicle for supply of oxygen and nutrition to the cartilage Further decreased oxygen tension is of significance for release of lysosomal enzymes (de Duve 1964)

The mechanical effect of synovitic joint effusion is discussed on p 21



Fig 8 Exposures of the same patient as in Fig 7 The film of the normal hip was exposed three minutes after the injection of contrast The exposure of the hip with osteoarthritis was made thirty minutes later Large quantities of contrast are left in the medullary space

In a second series of pressure measurements the same authors showed 5) that in patients with coxarthrosis the intraosseous pressure was always higher in the femoral head than in the neck (mean difference 10 8 mmHg)

In another study Arnoldi et al (1971) found that 6) in patients with coxarthrosis intertrochanteric osteotomy or cortical fenestration caused an immediate fall of intramedullary pressure in the femoral head and neck (osteotomy 17 6 mmHg and 13 5 mmHg respectively fenestration 21 5 mmHg and 15 9 mmHg respectively (mean values)) (Fig 9) In 10 of the 11 patients who complained of rest pain before the operation these pains had disappeared within 24 hours after the operation

Thus these investigations showed that patients with *late* stages of *painful* coxarthrosis invariably suffered from intraosseous venous stasis and hypertension in the bone marrow of the proximal femur and the changes were most pronounced near the hip joint The pressure in the extraosseous and extracapsular veins was not affected Later investigations have shown the same findings in patients with various forms of painful secondary coxarthrosis

They observed that 1) the intraosseous pressure in normal bone marrow was always higher than the pressure in the extraosseous veins of the region (mean difference 6 8 mmHg) 2) The intraosseous pressure was always higher in the arthritic hip than in the healthy hip (mean difference 29 7 mmHg) (Fig 6) 3) High intraosseous pressure coincided with phlebographic signs of impaired venous drainage from the upper end of the femur (intramedullary retention of contrast material and disappearance of the veins draining the femoral head (vv retinaculares) (Fig 7 and Fig 8) 4) Patients with high intraosseous pressures (<40 mmHg) always complained of characteristic pain at rest while patients with lower pressures did not suffer from this symptom



Fig 7 Bilateral intraosseous phlebography from patient with unilateral coxarthrosis exposed thirty seconds after bilateral injection of 8 millilitres Isopaque Cerebral In the normal hip the contrast material leaves the intraosseous space without noticeable filling of intraosseous vessels and is observed in the normal drainage veins In the hip with severe osteoarthritis the contrast is seen in large tortuous intraosseous veins extending far down into the femoral shaft

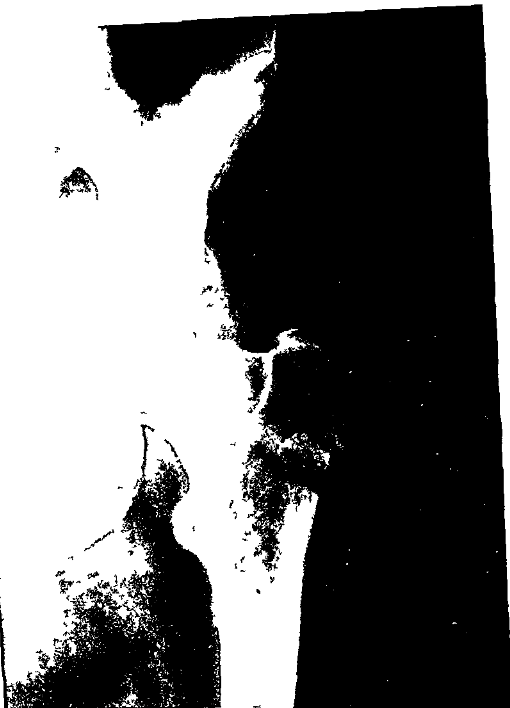


Fig 10 Hip joint from patient with the intraosseous engorgement pain syndrome after fenestration of the femoral neck

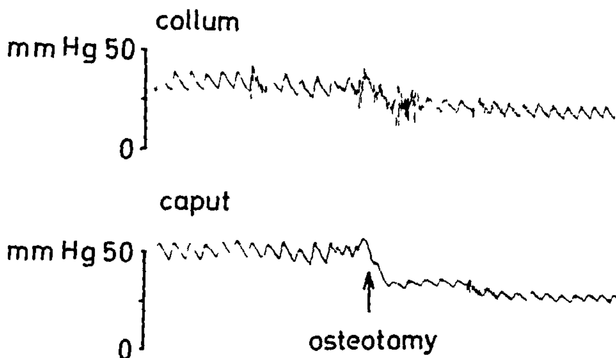


Fig 9 Pressure tracing from the femoral head and neck before and after subtotal intertrochanteric osteotomy

The intraosseous engorgement pain syndrome The finding that the characteristic rest pain of coxarthrosis seemed to be connected with intraosseous venous stasis and hypertension focussed our attention on this symptom

In a series of investigations on patients with various painful conditions in the knee region Arnoldi et al (1975) found that patients with rest pain (with or without osteoarthritis) showed a higher intraosseous pressure in the proximal part of the tibia or the lower part of the femur than patients without rest pain (with or without osteoarthritis) They observed that the patients with rest pain and high intraosseous pressure but without visual or clinical signs of osteoarthritis generally belonged to a younger age group than patients with gonarthrosis Later studies of this condition (Lemperg & Arnoldi 1978 Arnoldi et al in press 1979 b) showed that the high pressures were accompanied by intraosseous venous stasis that the intraosseous engorgement pain syndrome could be located to the hip as well as to the knee region (Fig 10 and 11) and that roentgen examination often showed a state of juxtaarticular osteopenia in these patients instead of the sclerotic appearance characteristic of osteoarthritis

inhibit the function of the quadriceps femoris muscle and lead to atrophy and flexion contracture (De Andrade et al 1965)

In human coxarthrosis the habitual contracture is flexion outward rotation and adduction which is also the position with the greatest joint volume due to maximal relaxation of the fibrous capsule One of the very early clinical signs of coxarthrosis and the intraosseous engorgement pain syndrome is pain on inward rotation in flexion If this symptom is analysed carefully it becomes obvious that the pain increases with increasing rotation The movement from maximum inward rotation back into neutral is accompanied by relief of pain Inward rotation reduces the volume of the hip joint and if effusion is present the intraarticular pressure should reach its maximum in this position

INTERDEPENDENCE BETWEEN INTRAARTICULAR AND INTRAOSSEOUS PRESSURE

Theoretically intraosseous stasis and hypertension could be explained as the effect of blockage of flow through the draining vessels from the weight bearing area of the femoral head and the haemodynamic changes in the bone marrow might be secondary to high pressure in the joint cavity due to synovitic effusion

Own investigations

Although the circumstantial evidence of interdependence between intraarticular and intraosseous pressure is impressive direct experimental evidence of this relationship has been lacking In order to investigate the reaction of intraosseous pressure to variations in intraarticular pressure we measured the pressure in the bone marrow of the femoral condyle of healthy rabbits before during and after a known rise of pressure in the knee joint (Arnoldi et al 1979 b)

As in human subjects the intraosseous pressure is normally somewhat higher than the intraarticular pressure Injection of fluid into the knee joint was accompanied by an immediate rise of intraarticular pressure and followed by a slower rise of pressure in the bone marrow of the femoral condyle (Fig. 12 and Fig 13) The results indicated a blockage of venous outflow through the intraarticular drainage vessels with continued arterial inflow to the bone marrow



Fig 11 ^{99m}Tc polyphosphate scintigraphy of both hips from the patient shown in Fig 10 (before operation)

Discussion

The cause of intraosseous stasis and hypertension

Our findings by means of intraosseous and intravenous pressure measurements in patients with coxarthrosis indicate that the blockage of venous drainage from the femoral head is located somewhere in or just outside the cortex Pressure measurements from extraosseous and extracapsular veins including the circumflex veins have shown normal findings (Fig 6 and Fig 22) The observations by Phillips et al (1967) seem to exclude venous thrombosis as a cause of blockage They found that intraosseous phlebography repeated 12 20 months after intertrochanteric osteotomy showed reopening of the normal drainage vessels from the femoral head in a number of patients Their phlebograms show no signs that this reopening was due to recanalisation of thrombosed veins

The retinacular veins leave the femoral head just distal to the cartilage border and until they join the circumflex veins their course is intraarticular The pressure in these veins lies between about 10 mmHg (the pressure in the normal bone marrow) and 5 mmHg (the pressure in the large extraosseous veins) As the studies on the synovium indicated and as direct measurements from other joints have shown (Eyring & Murray 1964) the intraarticular pressure increases when the volume of synovia increases or when the joint space is reduced A rise of intraarticular pressure in the order of 10 to 15 mmHg is sufficient to impede the flow through the intraarticular veins unless the perfusion pressure is raised

Contracture, joint volume and pain

From experiments on patients with rheumatoid arthritis of the knee joint we know that in the presence of joint effusion the intraarticular pressure is least in the mildly flexed position (Favreau & Laurin 1963 Eyring & Murray 1964 Jayson & Dixon 1970) which is the position spontaneously adopted by patients with effusions in the knee joint and gives least discomfort (Eyring & Murray 1964) In these experiments it was shown that further flexion of the knee produced extremely high intraarticular pressures that actually could rupture the joint capsule Further high intraarticular pressure could

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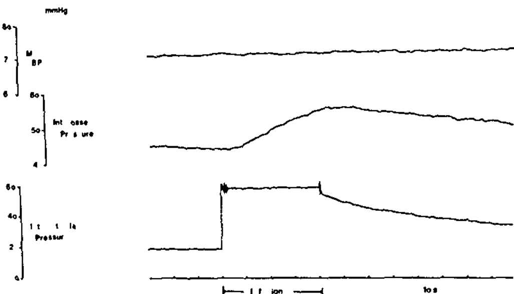


Fig 13 Tracing of intraosseous pressure increase induced by joint infusion of saline Simultaneous pressure curves from a single experiment

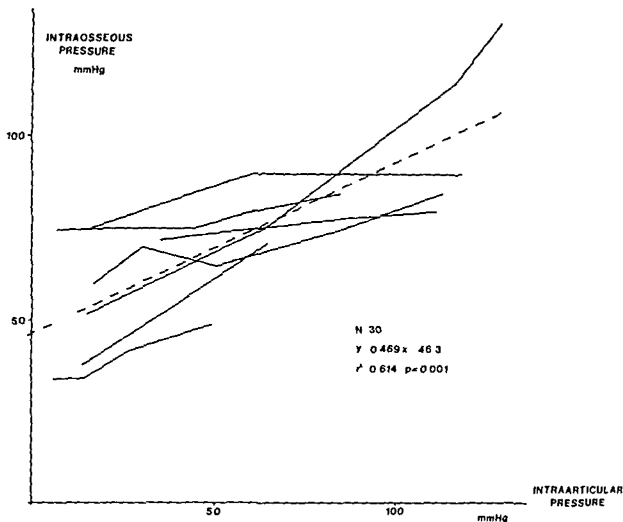


Fig 12 Intraosseous pressure as a function of intraarticular pressure A rise of intraarticular pressure resulted in a significant rise of pressure in juxtaarticular bone marrow ($p<0.001$)

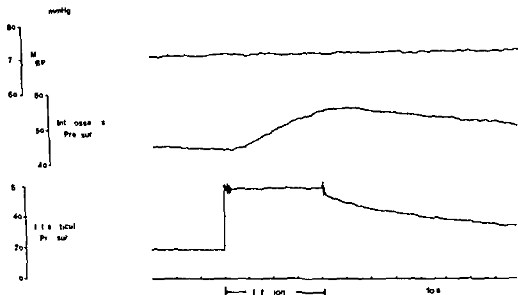


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Discussion

The experiments described above indicate that intraosseous stasis and hypertension may in fact be secondary to a joint effusion with high intraarticular pressure caused by synovitis

CHANGES IN SUBCHONDRAL BONE

The structural changes in subchondral bone in the osteoarthritic femoral head are fairly well known (Collins 1949 Sokoloff 1969 Radin et al 1970 Foss & Byers 1972 Jeffrey 1973) Roughly they are characterized by an attempt to repair dead trabeculae with increased bone formation The macroscopic results are seen as deformation of the head cyst formation increased radiodensity and building of osteophytes

Own investigations

Quantitative histological analysis of articular cartilage and subchondral bone

In order to quantify the alterations in subchondral bone and to compare the changes with the severity of the cartilage lesions a quantitative histological analysis of articular cartilage and subchondral bone from osteoarthritic and normal human hips was performed (Reimann et al 1977)

The analysis was based on 12 femoral heads six osteoarthritic and six controls The cartilage was graded according to the histological histochemical system of Mankin et al (1971) using the Safranin O staining method The subchondral bone was analysed to establish the percentage of trabecular osteoblastic and osteoclastic areas The trabecular bone area measurements were made with point-counting method (Harris & Weinberg 1972) and for osteoblastic and osteoclastic area counts the technique described by Melsen et al (1975) was used

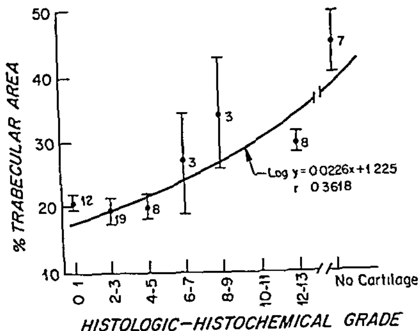


Fig 14 Diagram illustrating the relationship between the histological histochemical grade and the per cent of trabecular area

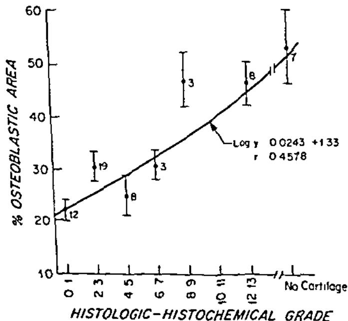


Fig 15 Diagram showing the relationship between histological-histochemical grade and the per cent of osteoblastic area

Discussion

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CHANGES IN SUBCHONDRAL BONE

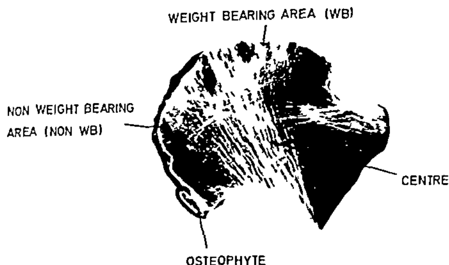
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ALKALINE PHOSPHATASE		ACID PHOSPHATASE	
WB	22 1 8 0sec	WB	412 138sec
NON WB	39 8 137sec	NON-V B	94 5*574sec
OSTEOPHYTE	26 6 4 7sec	OSTEOPHYTE	697 290sec
CENTRE	50 7±206sec	CENTRE	126 9 56 6sec

Fig 17 Radiographs of femoral head with osteoarthritis showing the different areas estimated The figures below illustrate the variations in the initial time according to the site studied

Frozen sections from 24 osteoarthritic femoral heads were prepared for semiquantitative analysis of the enzyme activity using Burstone s (1959) and Barka & Anderson s (1963) enzymo-histochemical methods The analyses showed that there were wide variations within the same femoral head for both enzymes with significantly higher activity in weight bearing than in non weight bearing areas and in subchondral bone compared with more central areas (Fig 17) Further the enzyme activity correlated directly with the severity of the cartilage lesions The findings seemed to be consistent with the morphological findings in the histological study

Distribution of ^{99m}Tc-phosphate compounds in osteoarthritic femoral heads (Christensen & Arnoldi in press 1979)

Femoral heads from 12 patients with osteoarthritis were examined Ten mCi ^{99m}Tc phosphate was given intravenously approximately 2 hours before total hip replacement and frozen sections were prepared Autoradiograms showed accumulation of ^{99m}Tc phosphate in the subchondral region of the weight bearing area of the femoral head and in the osteophytes (Fig 18 A and B) In the weight bearing area the uptake was particularly high in the walls of the cysts In the osteophytes the radionuclide was localized at the osteochondral junction

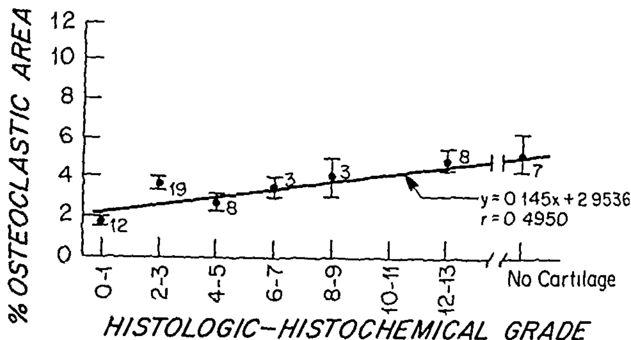


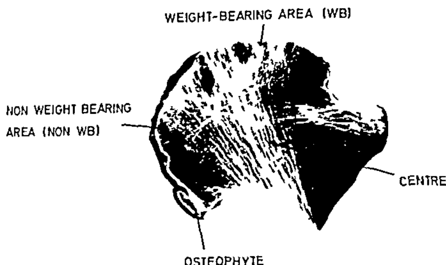
Fig 16 Graphic representation illustrating the relationship between histological histochemical grade and per cent of osteoclastic area

The data obtained showed wide variations in all parameters in the osteoarthritic specimens but consistently more marked alterations in the weight bearing areas The trabecular bone area as well as osteoblastic and osteoclastic areas were significantly larger in the osteoarthritic than in the control group (normal femoral heads obtained at autopsy or femoral heads removed after fracture of the femoral neck) (Fig 14 Fig 15 and Fig 16) By comparing the bony changes with the severity of the cartilage lesions from different areas within the same femoral head a correlation of moderate significance was found between the degeneration of the cartilage and sclerosis and hypermetabolism of the subchondral bone

Histochemical study of alkaline and acid phosphatase activity

To further elucidate the metabolic changes found in the subchondral osteoarthritic bone by histological examination a histochemical investigation was performed (Reimann & Christensen 1979)

Alkaline phosphatase was used as a marker enzyme for bone regeneration and acid phosphatase as a marker enzyme for bone resorption These enzymes were chosen as increased alkaline phosphatase activity has been demonstrated in regions of deposition of new bone (Jeffree 1959 Jeffree & Price 1965 Timmer et al 1968 Andersen 1970) and acid phosphatase – associated with the lysosomes in the osteoclasts – plays an important role in bone resorption (Burstone 1959 Doty & Scofield 1976)



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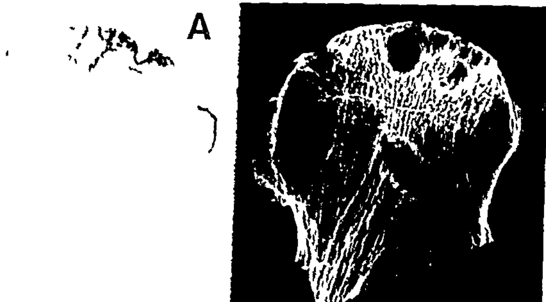


Fig 18 A *Autoradiogram from osteoarthritic femoral head from a patient given ^{99m}Tc polyphosphate preoperatively The radionuclide is predominantly accumulated at the cyst wall of the weight bearing area and at the osteochondral junction in the osteophytes*
B *Corresponding roentgenogram of a thin slice of the femoral head*

A quantitative study was performed from six different zones on a 10-micron thick section from each femoral head the six zones being the weight bearing area the non weight bearing area the osteophytes the central area the synovial membrane and the fibrous capsule These different zones were counted in a well counter The areas were determined by planimetry and the uptake per unit volume was expressed in proportion to the uptake per unit volume in the fibrous capsule The quantitative study confirmed the impression from the autoradiograms Thus the highest uptake was in the weight bearing area and in the osteophytes and the lowest in the synovial membrane and fibrous capsule (Fig 19)

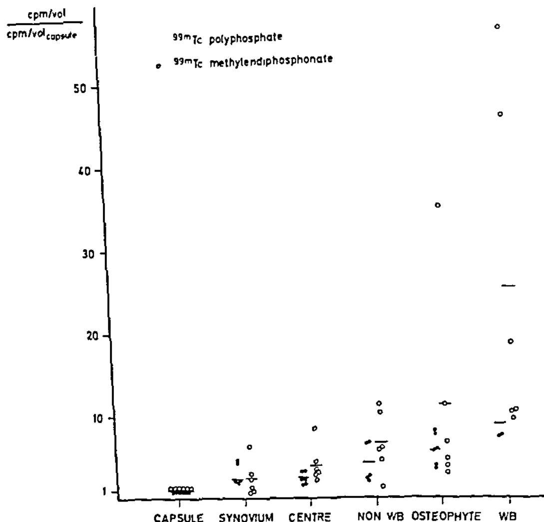


Fig 19 Target to-background ratio on different areas in twelve osteoarthritic femoral heads using the uptake of radionuclide in the fibrous capsule as background

To compare the distribution of the radionuclide with the morphology sections were stained with haematoxylin-eosin with the van Kossa technique for calcium phosphate and by Burstone s method for determination of alkaline phosphatase activity (Fig 20 A B and C) The morphological studies showed that the radionuclide accumulated in areas of new bone formation particularly enchondral ossification Histochemical staining for alkaline phosphatase activity showed that the distribution of this enzyme roughly corresponded to the deposition of the bone-seeking radionuclide Incidentally these investigations failed to produce evidence of callus formation in microfractures of subchondral bone trabeculae

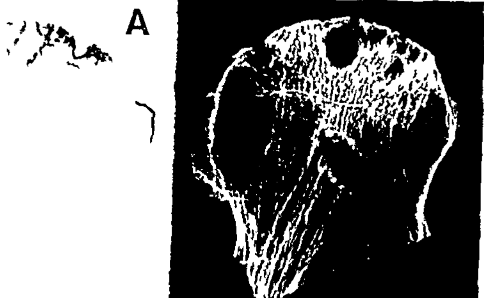
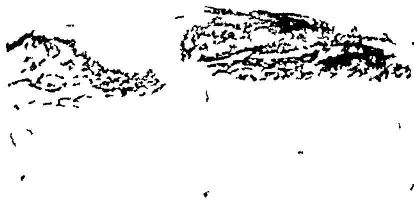


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C



C Alkaline phosphatase activity Magnification x 10

^{99m}Tc-polyphosphate scintigraphy in patients with osteoarthritis or the intraosseous engorgement pain syndrome (Arnoldi et al in press 1979 b)

Twenty five patients with painful conditions in the hip or knee region were examined by means of ^{99m}Tc polyphosphate scintigraphy intraosseous and intravenous pressure measurements and intra osseous phlebography Seventeen patients complained of typical rest pain in the hip or knee Ten of these suffered from severe osteoarthritis whereas seven fulfilled the criteria for the intraosseous engorgement pain syndrome (Lemperg & Arnoldi 1978) In the remaining eight patients the pain had a different character such as pain on loading or joint movements These pains were never present when the joint was completely at rest

All the patients with painful osteoarthritis or the intraosseous engorgement pain syndrome showed intraosseous venous stasis and hypertension in juxtaarticular bone marrow and increased uptake of the radionuclide over the affected joint (Fig 11 and Fig 21) This complete correlation between impaired drainage increased pressure and increased uptake of the radio tracer was not observed in patients with pain due to other causes

A



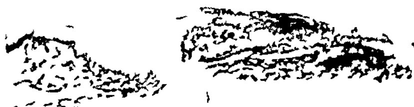
Fig 20 A Fibrocartilage at the articular surface with enchondral ossification Autoradiogram (^{99m}Tc polyphosphate)

B



B *Van Kossa stain Magnification x 10*

C



C *Alkaline phosphatase activity Magnification x 10*

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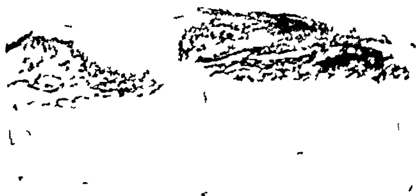
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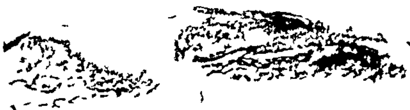
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Twenty five patients with painful conditions in the hip or knee region were examined by means of ^{99m}Tc polyphosphate scintigraphy intraosseous and intravenous pressure measurements and intra osseous phlebography Seventeen patients complained of typical rest pain in the hip or knee Ten of these suffered from severe osteoarthritis whereas seven fulfilled the criteria for the intraosseous engorgement pain syndrome (Lemperg & Arnoldi 1978) In the remaining eight patients the pain had a different character such as pain on loading or joint movements These pains were never present when the joint was completely at rest

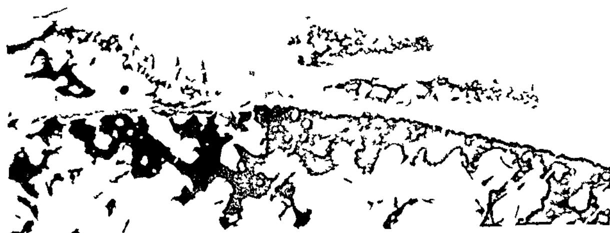
All the patients with painful osteoarthritis or the intraosseous engorgement pain syndrome showed intraosseous venous stasis and hypertension in juxtaarticular bone marrow and increased uptake of the radionuclide over the affected joint (Fig 11 and Fig 21) This complete correlation between impaired drainage increased pressure and increased uptake of the radio tracer was not observed in patients with pain due to other causes

A



Fig 20 A *Fibrocartilage at the articular surface with enchondral ossification Autoradiogram (^{99m}Tc polyphosphate)*

B



B *Van Kossa stain Magnification x 10*

C



C *Alkaline phosphatase activity Magnification x 10*

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Fig 21 ^{99m}Tc *polyphosphate scintigraphy from patient with unilateral painful coxarthrosis Compare Fig 11*

The authors concluded that the results may be an indication that the intraosseous engorgement pain syndrome and osteoarthritis are two stages of the same pathological process

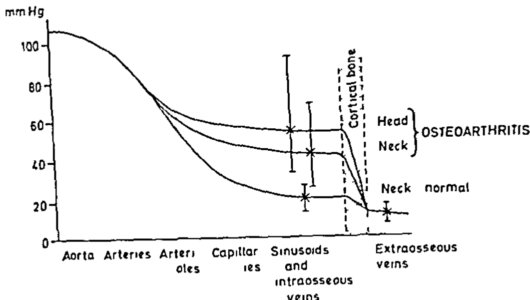


Fig 22 Schematic representation of intraosseous and extraosseous pressures in patients with unilateral painful coxarthrosis

Discussion

The conditions for capillary flow in the femoral head in coxarthrosis

Fig 22 shows intramedullary and intravenous pressures from patients with unilateral coxarthrosis together with mean arterial blood pressure measured on the upper arm The findings are inserted into a Landis curve of pressure distribution through the vascular system (Arnoldi et al 1972 a) The rate of flow through the capillary depends upon the diameter of the vessel and upon the pressure difference between the arterial and venous end of the capillary As seen in Fig 22 this pressure difference decreases in coxarthrosis and more so in the femoral head than in the neck Hyperplasia of the intramedullary arteries as demonstrated by Harrison et al (1953) may be a compensatory reaction to the high resistance to flow on the venous side of the circulation With a pressure distribution as shown in Fig 22 the end result is probably a reduced nutritional flow to bone tissue especially to the subchondral bone of the weight bearing area of the femoral head The slow clearance of radioactive NaI from the bone marrow of the femoral head demonstrated by Hernborg (1969) may be an indication of this state

There is however both clinical and experimental evidence that the intraosseous pressure – and thus the resistance to capillary flow – may vary considerably with circumstances If – as our findings induce us to believe – the characteristic rest pain is caused by excessively high pressure in the bone marrow the appearance of pain after exercise and disappearance after a period of rest indicate variations of pressure depending upon activity Fig 23 illustrates the effect of prolonged bed rest upon the marrow pressure

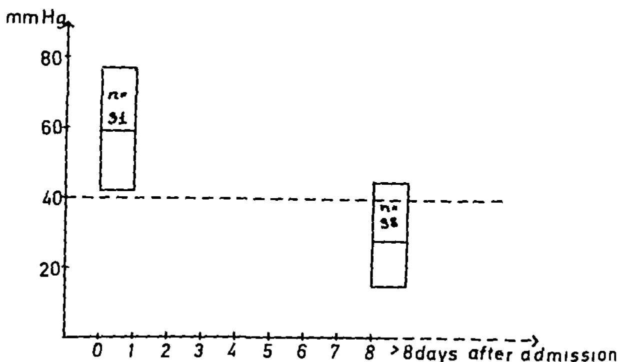


Fig 23 Intraosseous pressures from the femoral neck of hip joints with coxarthrosis and a history of severe aching rest pains Data from 69 hips Pressure in mmHg means and range 31 hips examined within 24 hours after the patient was admitted to hospital 38 examined after 8 22 days bed rest

Fig 22 indicates that under extreme circumstances the blood flow through subchondral bone marrow may virtually be at a stand still The effect upon cellular nutrition would be very much the same as blockage at the arterial end of the system Complete blockage of arterial inflow to bone results in death of the osteocytes within 8 to 24 hours (Rosingh & James 1969) Thus clinical observations as well as experimental findings indicate considerable periodical variations in the amount of oxygen available to the cells in the femoral head

The effect of reduced nutritive capillary flow on the bone structure of the femoral head

The finding of Hernborg (1969) of a reduced clearance of radioactive NaI from the femoral head in osteoarthritis and the intraosseous stasis and hypertension demonstrated by others indicate a reduced blood flow through the bone marrow of the femoral head in spite of continued arterial inflow This would most probably result in a reduced PO_2 in the region Direct measurements of oxygen tension in the bone marrow are surprisingly few but some evidence of reduced oxygen tension has been presented (Brookes 1970 Pujol et al 1973)

The histological picture of juxtaarticular bone in coxarthrosis is a mixture of bone death and new bone formation Several authors are of the opinion that venous stasis and reduced oxygen tension are the factors responsible for new bone formation (Harrison et al 1953 Pistolesi 1962 Abdalla & Harrison 1966 Phillips et al 1967 Arnoldi et al 1972 b) The investigations reported here indicate that the various phases of bone death and new bone formation might correlate with varying conditions for

cellular nutrition which in their turn are dependent upon varying degrees of resistance to flow from the drainage vessels of the weight bearing area of the femoral head

Our investigations point to the weight bearing area as the place where the changes from normal are most pronounced We are convinced that mechanical factors play an important role in the deformation of the joint that is so obvious in coxarthrosis However not all these features are directly explained by the effect of mechanical forces (e g osteophytes) Our investigations also stress the fact that the weight bearing area is the part of the femoral head that is drained by the superior retinacular veins and the part where the effects of venous stasis are most pronounced In our opinion the question of the relative importance of mechanical forces and weakening of bone structure due to circulatory deficiency for the deformation seen in osteoarthritic joints is still unanswered Theoretically it is quite feasible to assume that mechanical forces are only able to cause deformation of a joint if they act upon tissues previously weakened by degenerative changes produced by circulatory derangement

Are the vascular changes in subchondral bone marrow an early or late factor in the development of coxarthrosis?

Intraosseous stasis and high pressure in the vessels of the subchondral bone marrow are generally regarded as late and secondary manifestations of coxarthrosis which can be explained as a consequence of cartilage and bone changes (Freeman 1972) It is true that demonstration of vascular changes in the late stages of coxarthrosis does not necessarily indicate that these changes initiated the process leading to clinical osteoarthritis

However several well known clinical facts combined with recent findings indicate that haemodynamic changes in juxtaarticular bone may – after all – be a very early and perhaps causative factor in the development of the *skeletal* changes characteristic of osteoarthritis

1) The clinical observation that synovitis is a very common precursor to clinical osteoarthritis combined with the finding that increased intraarticular volume and pressure is followed by an increase of pressure in juxtaarticular bone marrow (Arnoldi et al 1979 a)
2) The experimental findings by Abdalla & Harrison (1966) that marrow stasis and high intramedullary pressure produced radiological and histological changes in cartilage and subchondral bone in albino rats that were consistent with those of human osteoarthritis
3) The observation that long standing ambulatory hypertension in patients with chronic venous insufficiency leads to skeletal changes of the same character as seen in osteoarthritis (Arnoldi et al 1972 b)
4) The observation that intraosseous stasis and hypertension may be observed in younger people with synovitis and pain but without signs of cartilage destruction (the intraosseous engorgement pain syndrome)

ARTICULAR CARTILAGE

The changes of articular cartilage in osteoarthritis are progressive with advancing disease leading to complete loss of tissue Most investigators are of the opinion that "degeneration" of this tissue is primary in the pathogenesis of osteoarthritis Over the years a sizable part of the literature has been

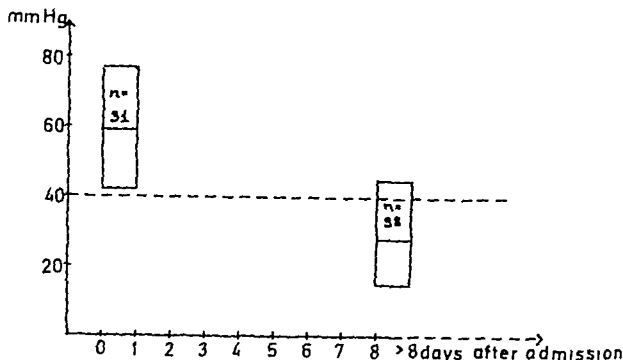


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Numerous reports have been concerned with investigations of biochemical changes in the matrix of articular cartilage and a reduction in the amount of glycosaminoglycans as well as alterations in quality have been consistent findings in osteoarthritis (Mathews & Glagov 1966 Mankin & Lippiello 1970 and 1971 Bjelle et al 1972 Lust & Pronsky 1972 and many others) but parallel with this reduction an increased synthesis of glycosaminoglycans was observed when $^{35}SO_4$ was incorporated (Collins & McElligot 1960 Mankin et al 1971 Eronen et al 1978)

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Own investigations

We have used this grading system to define the severity of the changes in articular cartilage from osteoarthritic femoral heads in various studies of the subchondral bone in order to compare the alterations in cartilage and subchondral bone (Reimann et al 1977 Reimann & Christensen 1979)

Differential histochemical staining of glycosaminoglycans in osteoarthritic cartilage

In another study (Christensen & Reimann in Press) we performed a histochemical analysis of articular cartilage from osteoarthritic femoral heads using Safranin 0 Alcian Blue CEC and Toluidine Blue at different pH values The purpose of the study was to demonstrate the presence and amount of chondroitin sulphate and keratan sulphate in the cartilage matrix and its distribution compared with normal cartilage

Safranin 0 was used to classify the degree of the osteoarthritic changes in cartilage according to the grading system of Mankin et al (1979) Alcian Blue with critical electrolyte concentration principle (Scott & Dorling 1965) was used to differentiate chondroitin 4/6 sulphate from keratan sulphate (Laurent & Scott 1964 Scott 1967) Toluidine Blue at different pH values is a metachromatic staining and as shown by Krygier & Kasprzyk (1961) and Spicer (1962) persisting metachromasia at pH 1 5 indicates presence of sulphated glycosaminoglycans while carboxyl groups lose their metachromasia at pH 3

These investigations showed that the degree of cartilage degeneration in osteoarthritis varied considerably from site to site within the same femoral head Pronounced changes were seen in weight bearing areas whereas less severe changes were present in non weight bearing areas Reduction in staining ability was seen first and most distinctly at the surface Apart from the loss of staining for glycosaminoglycans the osteoarthritic cartilage was characterized by increased territorial staining of chondroitin sulphate (Alcian Blue with 0 4 M $MgCl_2$) especially round cell clusters (Fig 24 A and B) Further keratan sulphate was found to be located more basically than chondroitin sulphate In the cartilage of osteophytes practically only chondroitin sulphate was present The increased territorial staining of chondroitin sulphate reflects an accelerated synthesis possibly an attempt to repair as seen in immature cartilage

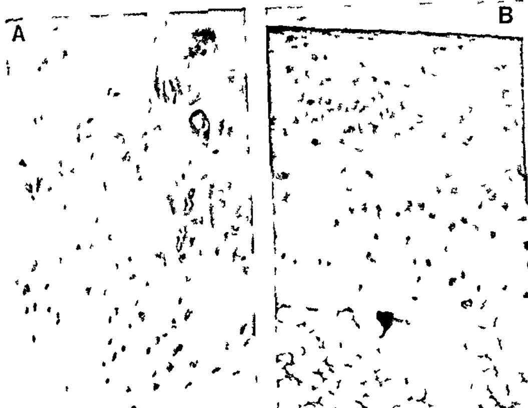


Fig 24 A *Osteoarthritic cartilage from a patient aged 50 years with intense territorial staining especially high around cell clusters Alcian Blue with 0 4 M $MgCl_2$ Magnification x 100*

B *Articular cartilage from a patient aged 73 with fracture of the femoral neck Alcian Blue with 0 4 M $MgCl_2$ Magnification x 100*

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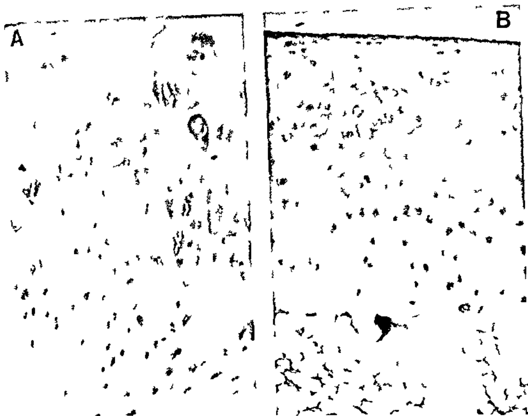


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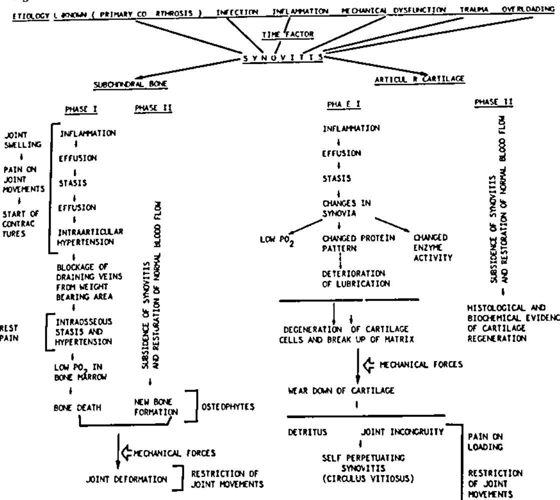
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Fig 5



Aetiology and time factor

The investigations reported here have mainly been concerned with the pathomechanism of primary or idiopathic coxarthrosis and the intraosseous engorgement pain syndrome However intraosseous pressure measurements and phlebography have been performed on a considerable number of patients

Discussion

The choice of our investigations on articular cartilage from human osteoarthritic femoral heads was largely determined by our resources and have first and foremost been an attempt to determine whether a relationship exists between changes in cartilage and subchondral bone Such a relationship has been suggested by means of biomechanical considerations (Radin et al 1973 Pugh et al 1974) and demonstrated as described above by quantitative histological analyses (Reimann et al 1977) Further it has been shown that the histological changes from osteoarthritic femoral heads evaluated by the grading system of Mankin et al (1971) correlate with biochemical and enzyme abnormalities of the osteoarthritic cartilage (Ehrlich et al 1973) In our studies these correlations were most pronounced in the weight bearing area

Articular cartilage has no blood vessels of its own Most investigators are of the opinion that cartilage is supplied with oxygen and nutrition through the vessels of the synovium via the synovial fluid and that the subchondral intraosseous vessels are of little importance in this respect

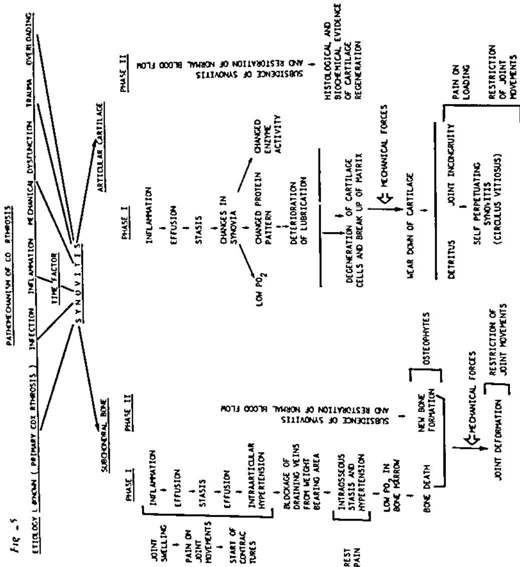
As discussed previously inflammation and stasis in the synovium reduce the rate of flow through the synovial vessels and increase the permeability of the capillary wall One result of these changes is a lowering of oxygen tension in the synovial fluid (Lund Olesen 1970) The protein and enzyme patterns are altered (see above) and striking changes in glycogen metabolism have been noted (Treuhaft & McCarty 1971 Lane et al 1977) At the same time the lubricating function of the synovia probably is impaired (Reimann 1976)

These changes in cartilage environment seem to us a reasonable – if still theoretical – cause of the changes observed in cartilage cells and matrix Mechanical forces undoubtedly play an important part in the wear and tear that leads to tissue waste but – as was the case in the question of changes in subchondral bone – we find it difficult to accept mechanical forces as primary causes of cartilage damage To us the clinical course of osteoarthritis as well as the experimental evidence suggest that mechanical force is only able to damage cartilage that is weakened by other causes

The evidence of our own investigations indicates that the changes observed in articular cartilage and subchondral bone are parallel reactions to the same primary pathological process

GENERAL DISCUSSION

The findings in patients with osteoarthritis and the engorgement pain syndrome by means of intraosseous phlebography and pressure measurements combined with the results of a series of studies on the effects on the mesenchymal tissues of the ankle region of dysfunction of the venous pump of the calf in patients with chronic venous insufficiency (Arnoldi 1964 Arnoldi & Linderholm 1971) especially the changes of the ankle skeleton and joint (Arnoldi et al 1972 b) led to the working hypothesis sketched in Fig 1 The results of the studies reported here and reports from the literature are *tentatively* correlated in the hypothesis shown in Fig 25



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The investigations reported here have mainly been concerned with the pathomechanism of primary or idiopathic coxarthrosis and the intraosseous engorgement pain syndrome. However intraosseous pressure measurements and phlebography have been performed on a considerable number of patients

with coxarthrosis secondary to rheumatoid arthritis Legg Calvé Perthe s disease and trauma and painful secondary coxarthrosis after these disorders shows the same intraosseous stasis and hyper tension as found in idiopathic coxarthrosis We therefore assume the pathomechanism to be more or less identical in primary and most forms of secondary coxarthrosis Their clinical course may be strikingly different, ranging from the silent period between the congenital hip dislocation and the appearance of clinical osteoarthritis decades later to the rapid development of secondary coxarthrosis after trauma or rheumatoid arthritis These time factor differences have probably something to do with the severity of the aetiological factor Apart from the specific effect of the rheumatoid inflammation on e g the enzyme activity in the joint patients with rheumatoid arthritis show the lowest synovial oxygen tension measured As mentioned above we believe primary coxarthrosis to be the end result of a series of attacks of synovitis sometimes stretching over a long period of years In this connection it may be mentioned that in the ankle joint skeletal sclerosis and osteophyte formation as well as genuine ankle joint osteoarthritis usually appeared decades after the attack of thrombophlebitis of the deep veins of the extremity responsible for the dysfunction of the venous pump of the calf and the high pressure in the intra and extraosseous veins of the ankle (Arnoldi et al 1972 b)

Synovitis and the developments in juxtaarticular bone (Fig 25)

The synovial membrane seems to react to any abnormal stimulus with essentially the same inflammatory reaction combined with effusion The clinical examples are legion The early synovial reaction is combined with a state of arterial hyperaemia not only of the synovial membrane but also in juxtaarticular bone where its effect on bone metabolism becomes visible on the isotope scintigram

In early cases of clinical synovitis the X rays are usually normal Occasionally especially in the more severe cases they show a state of juxtaarticular osteopenia The early stage of synovitis is mainly characterized by increased arterial inflow to the structures of the joint also in cases that later develop into clinical osteoarthritis This assumption seems to be supported by preliminary results from investigations on artificially induced osteoarthritis on animals (to be published)

The volume increase of synovial membrane and effusion result in increased intraarticular pressure The effect on the synovial membrane is venous stasis and – as long as the arterial inflow is intact – further joint effusion As shown in the experiments on rabbit joints a rise of intraarticular pressure is followed by a rise of intraosseous pressure In the hip joint this must be due to compression of the retinacular veins as they pass from the weight bearing part of the femoral head through the joint

In the proximal part of the femur blockage of the draining vessels leads to intraosseous stasis and hypertension Although the conditions for capillary flow through the femoral head seem to vary e g with physical activity the findings indicate that the resistance to flow occasionally becomes so great that the oxygen supply to the osteocytes fails The result is bone death

Rest physical treatment and medication seem to be effective in the treatment of many cases of synovitis Reduction of joint swelling and intraarticular pressure may restore the drainage through the retinacular veins and improve the conditions for bone marrow blood flow The characteristic histological findings of new bone deposited on dead trabeculae could be the result of this improvement of capillary flow

Regional bone necrosis and new bone formation leave the femoral head vulnerable to deformation by mechanical forces

Synovitis and changes in articular cartilage (Fig 25)

Increased permeability of the capillaries of the synovium caused by inflammation and later by mechanical stasis results in important changes in the synovial fluid which is the vehicle for the supply of oxygen and nutrition to the articular cartilage The changes noted in Fig 25 are probably just af few of the changes actually taking place However if the fact holds true that tissue degeneration and death are the end results of a lack of oxygen this factor alone should be sufficient to explain the fate of cartilage in osteoarthritis Even if there should be some foundation for the opinion held by some authors that the basal layers of cartilage are supplied by the subchondral vessels the circulatory derangement in subchondral bone would embarass this source of supply

We think that the circumstantial evidence supporting our assumption that cartilage degeneration is due to biochemical changes in the synovial fluid is logically impressive We are however aware that as far as we know this assumption has not been proved by experimental evidence although Abdalla & Harrison (1966) found signs of cartilage disorganisation as a result of induced venous stasis and hypertension In our studies of the literature on cartilage research we have noted that in spite of all the accumulated special knowledge the ultimate cause of the osteoarthritic changes is generally conceived of as some vague "mechanical dysfunction

In our opinion mechanical forces are important in the pathomechanism of osteoarthritis but their main role comes late in the process when the cartilage is already weakened by tissue degeneration ultimately due to changes in cellular environment If this course of events is accepted it is easier to explain why idiopathic coxarthrosis is so often unilateral why the ankle joints are so rarely affected etc

When the mechanical forces become effective the devitalized cartilage is exposed to the wear and tear that results in complete tissue waste erosion and denudation of the joint surface The detritus of the worn-down cartilage is caught in the plicae of the synovium and helps to perpetuate the pathological process in this membrane

Other causes of coxarthrosis

We would like to emphasize here that the pathomechanism suggested in this paper and schematically presented in Fig 25 is but one of several pathological processes that may lead to coxarthrosis In this mechanism the key feature is vascular derangement due to high resistance on the venous side of the capillary network but with intact arterial inflow to the structures of the joint

In certain forms of osteoarthritis a local arterial failure plays an important role in the pathomechanism This is the case in coxarthrosis secondary to necrosis of the femoral head after intracapsular fracture of the neck Bone necrosis due to arterial blockage is probably also important for the development of osteoarthritis after transplantation surgery and steroid medication in immunosuppression in certain cases of osteoarthritis in alcoholics and possibly in other diseases

Correlation of clinical signs and symptoms to the developmental stages of coxarthrosis

In Fig 25 we have made an attempt to correlate the clinical signs and symptoms of coxarthrosis with the various stages of the pathological process While some of these correlations are too obvious to deserve comment a few words on the subject of pain seem necessary

with coxarthrosis secondary to rheumatoid arthritis Legg Calvé Perthe s disease and trauma and painful secondary coxarthrosis after these disorders shows the same intraosseous stasis and hyper tension as found in idiopathic coxarthrosis We therefore assume the pathomechanism to be more or less identical in primary and most forms of secondary coxarthrosis Their clinical course may be strikingly different ranging from the silent period between the congenital hip dislocation and the appearance of clinical osteoarthritis decades later to the rapid development of secondary coxarthrosis after trauma or rheumatoid arthritis These time factor differences have probably something to do with the severity of the aetiological factor Apart from the specific effect of the rheumatoid inflammation on e g the enzyme activity in the joint patients with rheumatoid arthritis show the lowest synovial oxygen tension measured As mentioned above we believe primary coxarthrosis to be the end result of a series of attacks of synovitis sometimes stretching over a long period of years In this connection it may be mentioned that in the ankle joint skeletal sclerosis and osteophyte formation as well as genuine ankle joint osteoarthritis usually appeared decades after the attack of thrombophle bitis of the deep veins of the extremity responsible for the dysfunction of the venous pump of the calf and the high pressure in the intra and extraosseous veins of the ankle (Arnoldi et al 1972 b)

Synovitis and the developments in juxtaarticular bone (Fig 25)

The synovial membrane seems to react to any abnormal stimulus with essentially the same inflammatory reaction combined with effusion The clinical examples are legion The early synovial reaction is combined with a state of arterial hyperaemia not only of the synovial membrane but also in juxtaarticular bone where its effect on bone metabolism becomes visible on the isotope scintigram

In early cases of clinical synovitis the X rays are usually normal *Occasionally especially in the more* severe cases they show a state of juxtaarticular osteopenia The early stage of synovitis is mainly characterized by increased arterial inflow to the structures of the joint also in cases that later develop into clinical osteoarthritis This assumption seems to be supported by preliminary results from investigations on artificially induced osteoarthritis on animals (to be published)

The volume increase of synovial membrane and effusion result in increased intraarticular pressure The effect on the synovial membrane is venous stasis and – as long as the arterial inflow is intact – further joint effusion As shown in the experiments on rabbit joints a rise of intraarticular pressure is followed by a rise of intraosseous pressure In the hip joint this must be due to compression of the retinacular veins as they pass from the weight bearing part of the femoral head through the joint

In the proximal part of the femur blockage of the draining vessels leads to intraosseous stasis and hypertension Although the conditions for capillary flow through the femoral head seem to vary e g with physical activity the findings indicate that the resistance to flow occasionally becomes so great that the oxygen supply to the osteocytes fails The result is bone death

Rest physical treatment and medication seem to be effective in the treatment of many cases of synovitis Reduction of joint swelling and intraarticular pressure may restore the drainage through the retinacular veins and improve the conditions for bone marrow blood flow The characteristic histological findings of new bone deposited on dead trabeculae could be the result of this improvement of capillary flow

Regional bone necrosis and new bone formation leave the femoral head vulnerable to deformation by mechanical forces

Synovitis and changes in articular cartilage (Fig 25)

Increased permeability of the capillaries of the synovium caused by inflammation and later by mechanical stasis results in important changes in the synovial fluid which is the vehicle for the supply of oxygen and nutrition to the articular cartilage The changes noted in Fig 25 are probably just af few of the changes actually taking place However if the fact holds true that tissue degeneration and death are the end results of a lack of oxygen this factor alone should be sufficient to explain the fate of cartilage in osteoarthritis Even if there should be some foundation for the opinion held by some authors that the basal layers of cartilage are supplied by the subchondral vessels the circulatory derangement in subchondral bone would embarass this source of supply

We think that the circumstantial evidence supporting our assumption that cartilage degeneration is due to biochemical changes in the synovial fluid is logically impressive We are however aware that as far as we know this assumption has not been proved by experimental evidence although Abdalla & Harrison (1966) found signs of cartilage disorganisation as a result of induced venous stasis and hypertension In our studies of the literature on cartilage research we have noted that in spite of all the accumulated special knowledge the ultimate cause of the osteoarthritic changes is generally conceived of as some vague mechanical dysfunction

In our opinion mechanical forces are important in the pathomechanism of osteoarthritis but their main role comes late in the process when the cartilage is already weakened by tissue degeneration ultimately due to changes in cellular environment If this course of events is accepted it is easier to explain why idiopathic coxarthrosis is so often unilateral why the ankle joints are so rarely affected etc

When the mechanical forces become effective the devitalized cartilage is exposed to the wear and tear that results in complete tissue waste erosion and denudation of the joint surface The detritus of the worn-down cartilage is caught in the plicae of the synovium and helps to perpetuate the pathological process in this membrane

Other causes of coxarthrosis

We would like to emphasize here that the pathomechanism suggested in this paper and schematically presented in Fig 25 is but one of several pathological processes that may lead to coxarthrosis In this mechanism the key feature is vascular derangement due to high resistance on the venous side of the capillary network but with intact arterial inflow to the structures of the joint

In certain forms of osteoarthritis a local arterial failure plays an important role in the pathomechanism This is the case in coxarthrosis secondary to necrosis of the femoral head after intracapsular fracture of the neck Bone necrosis due to arterial blockage is probably also important for the development of osteoarthritis after transplantation surgery and steroid medication in immunosuppression in certain cases of osteoarthritis in alcoholics and possibly in other diseases

Correlation of clinical signs and symptoms to the developmental stages of coxarthrosis

In Fig 25 we have made an attempt to correlate the clinical signs and symptoms of coxarthrosis with the various stages of the pathological process While some of these correlations are too obvious to deserve comment a few words on the subject of pain seem necessary

Patients with coxarthrosis may suffer from different qualities of pain Most of them complain of pain when the joint is moved especially when the limits of movements are approached Pain on loading is equally common Rest pain is especially typical of coxarthrosis It is characteristic for the pain in coxarthrosis that it tends to radiate down the thigh to the knee region

Cartilage does not contain nerves but sensitive nerve endings are found in the synovium and the fibrous capsule as well as in the bone marrow where the nerves are found together with the blood vessels Recently Reimann & Christensen (1977) demonstrated a higher density of nerves in osteoarthritic subchondral bone marrow than in normal and ascribed the increase to the hyper vascularity of osteoarthritis

Joint distension by effusion may in itself be painful and the pain increases when the swollen joint is moved Stretching of the capsule and pinching of swollen synovium are obvious causes of pain However the reaction of intraosseous pressure to rise in intraarticular pressure brings another pain mechanism into focus By now most authors agree that rest pain is due to intraosseous stasis and hypertension (Arnoldi et al 1971 Bulstrode 1976) The threshold for pain seems to vary individually (Lemperg & Arnoldi 1978) but in most cases a rise above 40 mmHg will produce the characteristic rest pain

In a joint with effusion forced movements raise the pressure in the joint and may increase the intraosseous pressure above the threshold of pain

The intraosseous phlebograms showed dilation of all veins in the bone marrow of patients with painful coxarthrosis and the intraosseous engorgement pain syndrome Distension of veins is known to be connected with the bursting pain characteristic of patients with chronic venous insufficiency of the lower leg or idiopathic dysfunction of the venous pump of the calf (cruralgia orthostatica) (Arnoldi 1964 and 1976) Thus there are some indications that the distension of the veins caused by intraosseous venous stasis may be the factor responsible for the rest pain of osteoarthritis The findings that venous dilation and increased intraosseous pressure can be demonstrated not only in the femoral head and neck but also – although less pronounced – throughout the bone marrow of the femur might explain the pain radiating towards the knee joint characteristic of coxarthrosis

Future problems

In our opinion the results of the investigations presented in this paper give a reasonable basis for most of the developments sketched in Fig 25 The changes represent disturbances of an interacting mechanism and we have attached importance to the internal correlation of our findings At the time of writing our main problem – still poorly supported by experimental evidence – is the effect of changes in the composition of the synovial fluid upon articular cartilage However our choice of investigations has been determined by the resources of our laboratories and are not a result of any bias

One good reason for publishing the paper now is that it might provoke critical inquiry in centres with greater resources in the field of cartilage research

REFERENCES

Abdalla A B E & Harrison R G (1966) Observations on the reaction of tubular bone to venous stasis *J Anat* 100 627-638

Andersen H (1970) Histochemical investigations on the development of the joint and bone systems of the human foetus during the first half of prenatal period pp 48-69 Thesis Axelholm Copenhagen

Arlet J Ficat P & Sebbag D (1968) Intéret de la mesure de la pression intramédullaire dans la massif trochantérien chez l homme en particulier pour le diagnostic de l ostéonécrose fémoro-capitale *Rev Rhum* 35 250-256

Arnoldi C C (1964) The venous return from the lower leg in health and in chronic venous insufficiency *Acta Orthop Scand* Suppl 64

Arnoldi C C (1966) Venous pressure in patients with valvular incompetence of the veins of the lower limb *Acta Chir Scand* 132 628-645

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Arnoldi C C & Linderholm H (1971) Intracalcanean pressure in patients with different forms of dysfunction of the venous pump of the calf *Acta Chir Scand* 137 21 27

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Arnoldi C C (1976) Physiologie und Pathophysiologie des venosen Ruckstromes aus der unteren Extremität *In* Karl Sigg *Vari en Ulcus Cruris und Thrombose* 4 aufl pp 6-17 Springer Verlag Berlin Heidelberg New York

Arnoldi C C Reimann I Christensen S Bach & Mortensen S (1979 a) The effect of increased intraarticular pressure on juxtaarticular bone marrow pressure *IRCS Med Sci* 7 471

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Barka T & Anderson P J (1963) *Histochemistry* p 25 Harper and Row New York

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REFERENCES

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Arnoldi C C (1976) *Physiologie und Pathophysiologie des venösen Ruckstromes aus der unteren Extremität In* Karl Sigg *Vari en Ulcus Cruris und Thrombose* 4 aufl pp 6-17 Springer Verlag Berlin Heidelberg New York

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Barka T & Anderson P J (1963) *Histochemistry* p 25 Harper and Row New York

Bjelle A O Antonopopous C A Engfeldt B & Hjertquist S O (1972) Fractioning of the glycosaminoglycans of human articular cartilage on Ecteola cellulose in ageing and in osteoarthritis *Calc Tiss Res* 8 237 246

Brookes M (1970) Personal communication

Bulstrode C J (1976) Why are osteoarthritic joints painful? *J Roy Nav Med Serv* 62 5 16

Burnett D Wood S M & Bradwell A R (1976) Estimation of the Stokes radii of serum proteins for a study of protein movement from blood to amniotic fluid *Biochim Biophys Acta* 427 231 237

Burstone, M S (1959) Histochemical demonstration of acid phosphatase activity in osteoclasts *J Histochem Cytochem* 7 39-41

Christensen S Bach & Arnoldi C C (1979) Distribution of ^{99m}Tc phosphate compounds in osteoarthritic femoral heads *J Bone Jt Surg* (Am Vol) in Press

Christensen, S Bach & Reimann I Differential histochemical staining of glycosaminoglycans in the matrix of osteoarthritic cartilage Acta Path Microbiol A (in Press)

Collins D H (1949) *The pathology of articular and spinal diseases* pp 74 115 Edward Arnold & Co London

Collins D H & McElligot T F (1960) Sulphate ($^{35}SO_4$) uptake by chondrocytes in relation to histological changes in osteoarthritic human articular cartilage *Ann Rheum Dis* 19 318 330

De Anrade, J R Grant C & Dixon St J (1965) Joint distension and reflex muscle inhibition in the knee *J Bone Jt Surg* 47 313 322

De Duve C (1964) Lysosomes and cell injury *Symposium on injury inflammations and immunity* Ed by L Thomas J W Uhre & L Grant Baltimore

Doty S B & Scofield B H (1976) Enzyme histochemistry of bone and cartilage cells *Prog Histochem Cytochem* 8 1 38

Dryll, A Lansaman J Cazalis P Peltier A P & De Seze S (1977) Light and electron microscopy study of capillaries in normal and inflammatory human synovial membrane *J Clin Path* 30 556 562

Erlich M G Mankin H J & Treadwell B A (1973) Acid hydrolase activity in osteoarthritic and normal human cartilage *J Bone Jt Surg* 55 A 1068 1076

Eronen I Videman T Friman C & Michelsson J E (1978) Glycosaminoglycan metabolism in experimental osteoarthrosis caused by immobilization *Acta Orthop Scand* 49 329 334

Eyring E J & Murray W R (1964) The effect of joint position on the pressure of intra articular effusion *J Bone Jt Surg* 46-A, 1235 1241

Favreau J C & Laurin, C A (1963) Joint effusions and flexion deformities *Can Med Assoc J* 88 575 576

Foss M V & Byers P D (1972) Bone density osteoarthrosis of the hip and fracture of the upper end of femur *Ann Rheum Dis* 31 259 264

Freeman M A (1972) The pathogenesis of primary osteoarthrosis An hypothesis In *Modern Trends in Orthopaedics – 6* pp 40-94 Ed by Graham Apley Butterworths London

Goldhaft A D Wright L M & Pemberton R (1930) The production of hypertrophic arthritis by interference with the blood supply *Am J Med Sci* 180 386-397

Goldie I (1970) The synovial microvascular derangement in rheumatoid arthritis and osteoarthritis *Acta Orthop Scand* 40 751 764

Harris W H & Weinberg E H (1972) Microscopic method of measuring increase in cortical bone volume and mass *Calc Tiss Res* 8 191 196

Harrison M H M Schajowicz F & Trueta J (1953) Osteoarthritis of the hip A study of the nature and evolution of the disease *J Bone Jt Surg* 35 B 598-626

Haxthausen H (1936) Om pathogenesen af ulcus cruris varicosum *Nord Med* 12 1665 1670

Heerfordt J Vistisen L & Bohr H (1976) Comparison of ^{18}F and ^{99m}Tc polyphosphate in orthopaedic bone scintigraphy *J Nucl Med* 17 98-103
Helal B (1962) Osteoarthritis of the knee Thesis University of Liverpool
Hemborg J (1969) Elimination of Na ^{131}I from the head and the neck of the femur in unaffected and osteoarthritic hip joints *Arthr Rheum* 12 30-33
Hopsu V K & Glenner G G (1965) A histochemical enzyme kinetic system applied to the trypsin like amidase and esterase activity in human mast cells *J Cell Biol* 17 503 520
Hulth A (1959) Circulatory disturbances in osteoarthritis of the hip *Acta Orthop Scand* 28 81 89
Huth F Soren A Rosenbauer K A & Klein W (1973) Fine structural changes of the synovial membrane in arthrosis deformans *Virch Arch A Path* 359 201 211
Jayson M I V & Dixon A St J (1970) Intra articular pressure in rheumatoid arthritis of the knee III Pressure changes during joint use *Ann Rheum Dis* 29 401-408
Jeffrey A K (1973) Osteogenesis in the osteoarthritic femoral head *J Bone Jt Surg* 55 B 262 272
Jeffrey G M (1959) Phosphatase activity in the limb bones of growing rabbits *J Bone Jt Surg* 41 B 401-412
Jeffrey G M & Price C H (1965) Bone tumours and their enzymes *J Bone Jt Surg* 47 B 120-136
Kar N C Cracchiolo A Mirra J & Pearson C M (1976) Acid neutral and alkaline hydrolases in arthritic synovium *Am J Clin Path* 65 220-228
Krygier A & Kazimierz K (1961) The influence of hydrogen ion concentrations and some other ions on metachromasia in staining mucopolysaccharides with toluidine blue *Acta Med Polona* 2 123-145
Kushner I & Sommerville A (1971) Permeability of human synovial membrane to plasma proteins Relationship to molecular size and inflammation *Arthr Rhem* 14 560-570
Lane J M Brighton C T & Menkowitz B J (1977) Anaerobic and aerobic metabolism in articular cartilage *J Rheum* 4 334 342
Laurell C B (1966) Quantitative estimation of proteins by electrophoresis in agarose gel containing antibodies *Anal Biochem* 15 45 52
Laurent T C & Scott J E (1964) Molecular weight fractionation of polyanion by cetylpyridinium chloride in salt solutions *Nature* 202 661-662
Lemperg R K & Arnoldi C C (1978) The significance of intraosseous pressure in normal and diseased states with special reference to the intraosseous engorgement pain syndrome *Clin Orthop* 136 143 156
Lloyd Roberts G C (1953) The role of capsule changes in osteoarthritis of the hip joint *J Bone Jt Surg* 35 B 627-642
Lund Olesen K (1970) Oxygen tension in synovial fluids *Arthr Rheum* 13 769 776
Lust C & Pronsky W (1972) Glycosaminoglycan content of normal and degenerative articular cartilage from dogs *Clin Chim Acta* 39 281 286
Mankin H J & Lippiello L (1970) Biochemical and metabolic abnormalities in articular cartilage from human osteoarthritic hips *J Bone Jt Surg* 52 A 424-434
Mankin H J & Lippiello L (1971) The glycosaminoglycans in normal and arthritic cartilage *J Clin Invest* 50 1712 1719

Mankin H J Dorfman H Lipiello L & Zarins A (1972) Biochemical and metabolic abnormalities in articular cartilage from osteoarthritic human hips II Correlation of morphology with biochemical and metabolic data *J Bone Jt Surg* 53 A 523 537

Mathews B F & Glagov S (1966) Acid mucopolysaccharide pattern in aging human cartilage *J Clin Invest* 45 1103 1111

Melsen F Mosekilde L & Beck Nielsen H (1975) Kvantitativ histologisk undersøgelse ved metaboliske knoglelidelser *Ugeskr Læg* 137 933 935

Ménel P Ruffié R & Fournié A (1955) La phlébographie de la hanche dans les coxarthroses *Rev Rhum* 22 238 241

Nettelbladt E & Sundblad L (1959) Protein patterns in synovial fluid and serum in rheumatoid arthritis and osteoarthritis *Arthr Rheum* 2 144 151

Phemister D B (1940) Changes in bones and joints resulting from interruption of circulation *Arch Surg* 41 436-472

Phillips R S (1966) Phlebography in osteoarthritis of the hip *J Bone Jt Surg* 48 B 280 288

Phillips R S Bulmer J H Hoyle G & Davies W (1967) Venous drainage in osteoarthritis of the hip *J Bone Jt Surg* 49 B 301 309

Pistolesi G F (1962) Il circulo venoso profondo dell anca nell artrosi 9 Russegna internationale del film scientifico diduttico Universita di Padova Italy

Pridie K H (1952) The development of osteoarthritis of the hip joint *J Bone Jt Surg* 34 B 153

Pruzanski W Russel M L Gordon D A & Ogryzlo M A (1973) Serum and synovial fluid proteins in rheumatoid arthritis and degenerative joint diseases *Amer J Med Sci* 265 483-490

Pugh J W Radin E & Rose R M (1974) Quantitative studies of human subchondral cancellous bone Its relationship to the state of its overlying cartilage *J Bone Jt Surg* 56 A 313 321

Pujol M Tran M A & Arlet J (1973) Premiers résultats d une étude gasométrique de sang osseux trochantérien dans les coxopathies *Rev Rhum* 40 515 519

*Radin E L Paul I L & Tolkoff M J (1970) Sub*chondral bone changes in patients with early degenerative joint disease *Arthr Rheum* 13 400-405

Radin E L Parker G H & Pugh J W (1973) Response of joints to impact loading III Relationships between trabecular microfracture and cartilage degeneration *J Biomech* 6 51 57

Reimann I Stougaard J Northeved A & Johnsen S J (1975) Demonstration of boundary lubrication by synovial fluid *Acta Orthop Scand* 46 1 10

Reimann I (1976) Pathological human synovial fluids viscosity and boundary lubricating properties *Clin Orthop* 119 237 241

Reimann I & Christensen S Bach (1977) A histological demonstration of nerves in subchondral bone *Acta Orthop Scand* 48 345 352

Reimann I Mankin H J & Trahan C (1977) Quantitative histologic analyses of articular cartilage and subchondral bone from osteoarthritic and normal human hips *Acta Orthop Scand* 48 63 73

Reimann I & Christensen S Bach (1979) A histochemical study of alkaline and acid phosphatase activity in osteoarthritic synovial membrane *Scand J Rheum* 8 39-42

Reimann I & Christensen S Bach (1979) A histochemical study of alkaline and acid phosphatase activity in subchondral bone from osteoarthrotic human hips *Clin Orthop* 140 85 91

Reimann I Arnoldi C C & Nielsen O Saxtrup Permeability of synovial membrane to plasma proteins in human coxarthrosis Relation to molecular size and histological changes Clin Orthop (in Press)

Renkin E M (1977) Multiple pathways of capillary permeability *Circul Res* 41 735 743

Ropes M W & Bauer W (1953) *Synovial fluid changes in joint disease* pp 6-8 Harvard University Press New York

Roy S (1967) Ultrastructure of synovial membrane in osteoarthritis *Ann Rheum Dis* 26 517 527

Rösingh G E & James J (1969) Early phases of avascular necrosis of the femoral head in rabbits *J Bone Jt Surg* 51 B 165 174

Salvati E A Granda J L Mirra J & Wilson P D (1977) Clinical enzymatic and histological study of synovium in coxarthrosis *Internat Orthop* 1 39-42

Scott J E & Dorling J (1965) Differential staining of acid glycosaminoglycans (mucopoly saccharides) by Alcian Blue in salt solutions *Histochemie* 5 211 233

Scott J E (1967) On the use and abuse of the critical electrolyte concentration approach to the localization of tissue polyanions *J Histochem Cytochem* 15 11 113

Sokoloff L (1969) *The biology of degenerative joint disease* The University of Chicago Press Chicago

Spicer S S (1962) Histochemical differentiation of sulfated rodent mucins *Ann Histochem* 7 23 28

Timmer J Hadders H N Dardonk M J & Kondstaal J (1968) An experimental investigation into the development of callus and induced tumours in mice studies by histological and enzyme histochemical methods *Brit J Cancer* 22 422-436

Treuhaft P S & McCarty D J (1971) Synovial fluid pH lactate oxygen and carbon dioxide partial pressure in various joint diseases *Arthr Rheum* 14 475-484

Wardle E N (1964) Osteotomy of the tibia and fibula in the treatment of chronic osteoarthritis of the knee *Postgrad Med J* 40 536-542

Wilkinson M & Jones B S (1963) Evaluation of needle biopsy of synovial membrane *Ann Rheum Dis* 22 100-105

Willumsen L & Friis J (1975) A comparative study of the protein pattern in serum and synovial fluid *Scand J Rheum* 4 234 240

Wollenberg G A (1909) Die ätiologie der arthritis deformans im lichte des experimentes *Arch Orthop Mech Therp Unfallchir* 7 226-234

Zweifach B W (1940) The structural basis of permeability and other functions of blood capillaries *Cold Spr Harb Symposia Quant Biol* 8 216-223

JENS LANGER ANDERSEN

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An analysis of 240 cases of hemi- hinge and resurfacing arthroplasties

1 INTRODUCTION

While arthroplasty of the knee was attempted already 100 years ago the techniques used today are based on the pioneer work in the 1950s (McIntosh 1967 Shiers 1954 Walldius 1957 and McKeever 1959) During the 1970s the development and use of new designs for knee arthroplasty have developed exponentially at present more than 400 different designs are available on the market and in Sweden 1 000 arthroplasties are performed yearly It is not easy for the surgeon to choose between widely different concepts and methods for arthroplasty of the knee published results are confusing contradictory and difficult to interpret An important reason for this confusion is that most published series fail to make a distinction between osteoarthrosis and rheumatoid arthritis However, most patients subjected to arthroplasty of the knee because of arthrosis do not suffer from generalized arthropathy and the knee condition is focal (Ahlbäck 1968), whereas rheumatoids have a generalized disease characterized by poly-arthropathy with panarthritis The aim of this work was to compare the clinical results and identify complications and reasons for failures of three different arthroplasty methods using the hemi-hinge and resurfacing principles All patients had rheumatoid arthritis (RA) (Golding 1966) and population differences in the three materials were identified

SURGERY FOR RHEUMATOID ARTHRITIS OF THE KNEE IN LUND

From 1967 through 1976 more than 1 000 operations were performed for rheumatoid arthritis of the knee at the Department of Orthopaedic Surgery at the University Hospital of Lund Sweden Synovectomy was by far the most common operation (542 cases) For correction of deformities high tibial osteotomies were performed in 75 knees and capsulotomies in 60 Baker cysts were excised in 53 knees Up to 1973 27 arthrodeses were carried out (Brattström 1971)

This work analyses the result of 240 consecutive knee arthroplasties in rheumatoid arthritis performed in Lund 1967-1976 The material includes 67 McIntosh arthroplasties with observation time on an average 3 3 years (1 0-6 0) operated 1967-1972 64

II MATERIAL AND METHODS

All patients were admitted to the Department of Orthopaedic Surgery or Rheumatology at the University Hospital of Lund and operated at the Department of Orthopaedics The diagnosis of rheumatoid arthritis was established according to the American Rheumatoid Association s (ARA) criteria for classical definite and probable RA (Golding 1966) and will henceforth be termed RA

Preoperative status

Case records and patient interviews provided information about previous disease the preoperative ARA functional classification (Berglund et al 1973) and social status Preoperative degree of pain and dependence on walking or other aid were part of the status at admission recorded by the surgeon and the physiotherapist

This status included observations of exudate and capsular thickening femoro-patellar crepitation and decreased lateral mobility of the patella Sagittal instability was noted by the anterior drawer sign with the knee flexed 90° Lateral instability was measured with the knee flexed 5° (Hallén 1965) Range of movement of the knee was measured with a goniometer Unless otherwise indicated extension was always passive Varus and valgus was measured in the standing position using a goniometer an FT-angle of 174° was defined as neutral (Fig 2) The quadriceps power was measured as a breaking force on isometric contraction with 90° knee flexion and resistance applied immediately proximal to the talo-crural joint

Complications

Early complications during the operation and postoperatively within two months as well as late complications were identified from the case records and interviews

Status at follow-up

The author examined all patients Parameters were identical to what was described under preoperative objective status ESP was registered at follow-up for estimating disease activity

EVALUATION SYSTEM

The Insall's (1969) knee joint evaluation system was used throughout A good result is

Guépar arthroplasties with observation time on an average 2 7 years (1 1-4 3) operated 1972-1976 and 109 *Marmor arthroplasties* with observation time on an average 2 2 years (1 0-3 6) operated 1974-1976

These three arthroplasties represent three different replacement principles

The McIntosh prosthesis is a hemiprosthesis which resurfaces the tibial condyle and by a spacer effect can correct deformity and instability From 1967 through 1970, the McIntosh prosthesis was the only arthroplasty used in Lund and the indications were therefore quite liberal Attrition of the femoral condyles to a slight degree was not a contraindication Lateral instability and malposition in varus-valgus up to 30° were also accepted

The Guépar prosthesis is a simple *mechanical hinge cemented in the medullary cavity* The prosthesis has a fixed transverse axis of rotation, and stability is totally independent of the soft tissue of the knee constrained principle From 1972 through 1973, the Guépar hinge prosthesis was that most used at the clinic This was partly due to the existence of a pool of patients where an arthrodesis had been the only realistic alternative because the McIntosh prosthesis was insufficient Since 1974, the use of the Guépar prosthesis was substantially reduced following the introduction of the Marmor prosthesis

The Marmor prosthesis resurfaces the femur and the tibia and is thus a total prosthesis for the femoro-tibial (FT)-joints, having the same propensity as the McIntosh prosthesis to correct deformity and instability From 1974, this prosthesis totally replaced the McIntosh prosthesis and during 1975 and 1976, partly even the indication for using a Guépar prosthesis It was also used in younger patients

The McIntosh and Marmor prostheses do not decrease free movements between the femur and tibia and stability in the arthroplasty depends entirely on the ligaments and extra-articular soft tissue unconstrained principle

By the end of the period dealt with in this work, the Guépar prosthesis had been largely replaced by the Attenborough prosthesis, which represents the group of hemiconstrained prostheses that permit rotation between the *tibia and the femur* and a certain limited lateral instability

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equal to a low score (minimum 0, maximum 33 demerit points) Points are given for each of the parameters pain, use of walking aids, flexion, extension defect, varus or valgus deformity at weight-bearing, lateral instability and quadriceps weakness (Table I) The total is thus an expression of the deviation from normal The same value of points can however represent different combinations of pathologic findings The points allocated for a given parameter are chosen with regard to the functional consequences A total score between 0 and 2 is described as excellent, between 3 and 6 as good, between 7 and 10 as fair and 11 or more as poor On statistical analysis of the material the group with 0 to 6 points is called 'satisfactory and 7 or higher 'not satisfactory'

In using Weinfeld s point system it is important to bear in mind that the score for the specific knee reflects the deviation from a normal knee (0 point) and a knee that at follow-up has a score of 7 or more, thus being placed in the group 'not satisfactory', can be judged by both the surgeon and the patient as being improved The patient can, for instance, preoperatively score 14 points and at follow-up 7 points in spite of this improvement the case would still fall into the 'not satisfactory" group

Weinfeld s evaluation system was chosen because it is largely based on objective criteria and is numerical in nature Thus the risk of biased judgement arising from the patient s and the examiner s loyalty to the surgeons is reduced It facilitates comparison between pre- and postoperative status and comparison of results according to different replacement methods The system is well suited for data computing and statistical analysis A number of other evaluation systems exist and this makes comparison between different works extremely difficult (Andersson 1972) The Weinfeld s system has been used by Potter (1972) and Jani and Morscher (1973) for evaluation of arthroplasty with the McIntosh prosthesis

Table I

Weinfeld's evaluation system

	Points
Pain	
None or unimportant	0
After more than 200 m walking	1
After less than 200 m walking	3
Immediately at weight-bearing	6
Considerable pain at rest	7
Use of support at walking	
Can walk without support	0
Cane out-doors	1
Cane in-doors	2
Crutches all the time	4
Extension defect	
Extension defect ≦5°	0
Extension defect >5° - ≦15°	1
Extension defect >15° - ≦30°	2
Extension defect >30°	4
Flexion	
Flexion >80°	0
Flexion >60° - ≦80°	1
Flexion >30° - ≦60°	3
Flexion ≦30°	6
Medial or lateral instability	
Instability <10°	0
Instability ≧10° <20°	2
Instability ≧20°	4
Varus-valgus at weight-bearing	
Malposition <10°	0
Malposition ≧10° - <20°	2
Malposition ≧20° - <30°	3
Malposition ≧30°	4
Quadriceps power	
Quadriceps power N ≧200	0
Quadriceps power N ≧150 - <200	1
Quadriceps power N ≧100 - <150	2
Quadriceps power N <100	4

Sum of demerit points = result

Rating				
Excellent	0-2 points	0-6 points	Satisfactory*
Good	3-6 points		
Fair	7-10 points	7-33 points	Not satisfactory
Poor	11-33 points		

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Extension defect	
Extension defect $\leqq 5^\circ$	0
Extension defect $> 5^\circ - \leqq 15^\circ$	1
Extension defect $> 15^\circ - \leqq 30^\circ$	2
Extension defect $> 30^\circ$	4
Flexion	
Flexion $> 80^\circ$	0
Flexion $> 60^\circ - \leqq 80^\circ$	1
Flexion $> 30^\circ - \leqq 60^\circ$	3
Flexion $\leqq 30^\circ$	6
Medial or lateral instability	
Instability $< 10^\circ$	0
Instability $\geqq 10^\circ - < 20^\circ$	2
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Varus-valgus at weight-bearing	
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Quadriceps power	
Quadriceps power $N \geqq 200$	0
Quadriceps power $N \geqq 150 - < 200$	1
Quadriceps power $N \geqq 100 - < 150$	2
Quadriceps power $N < 100$	4

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Figure 1

Classification of FT-compartment destruction in rheumatoid arthritis of the knee



Fig 1a Narrowing of the articular space in the medial compartment



Fig 1b Obliteration of the articular space in the lateral compartment



Fig 1c Attrition of moderate degree in the medial compartment



Fig 1d Attrition of severe degree in the medial compartment

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Subjective status at follow-up

Pain at rest or at weight-bearing was recorded the latter in relation to walking distance Use of support at walking was recorded Details regarding medication during the observation period were noted Based on information concerning activities of daily living (ADL-status) and need for public assistance, the ARA functional classification was determined and the socio-economic status assessed Pain at weight-bearing, arthroplasties and arthrodeses performed in other major joints in the lower extremities were also registered The patients were asked for their opinion of the result of the operation

ROENTGEN MATERIAL

The analysis was based on the following roentgen examinations
Preoperatively Standard frontal and lateral projections of the knee and an axial projection of the femoro-patellar joints (FP-joints) in 30° of knee flexion were usually taken in the supine position, and frontal projections on weight-bearing in varus and valgus provocation according to Norman (Hagstedt 1974) Because of pain, synovitis, flexion contracture and varus and valgus malposition, extreme provocation was not always possible
At follow-up Similar examinations as preoperatively, axial projection of FP-joint only when clinically indicated For comparison of position of prosthetic components the immediate postoperative and the follow-up roentgen examinations were compared

Analysis of roentgen material

The author evaluated the roentgen material of the McIntosh and Guépar material The Marmor material was evaluated in co-operation with the Roentgenological Department II at the University Hospital of Lund (Niels Egund and Hildur Laurusdottir) Clinical and roentgenological observations were not correlated until all observations were registered and data analysed

Cartilage reduction and attrition in FT-joint preoperatively Analysis of the medial and lateral compartments were made on frontal projections of the knee in weight-bearing and varus provocation and valgus provocation, respectively

A simplified model of Ahlbäck s (1968) classification for gonarthrosis was used The simplification was adopted for the following reasons
1) RA as opposed to osteoarthrosis usually involves both FT-compartments In this work the destruction in the most pathological compartment was selected for classification
2) Destruction in RA does not develop uniformly through cyst formation and subchondral fractures bone attrition can be simulated even if total cartilage destruction is not present

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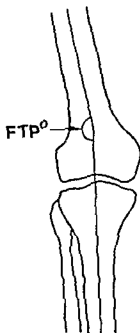


Fig 2 The FTP-angle was defined as the lateral open angle between the longitudinal axes of femur and tibia in the frontal exposure on weight-bearing and provocation in varus and valgus (Hagstedt 1974)

Analysis of roentgen material at follow-up

McIntosh

Destruction of the femoral condyles was judged on the basis of provoked frontal exposures at weight-bearing and a standard lateral exposure The FTP angle was assessed using the same methods as in the preoperative examination The position of the prosthesis was assessed on the basis of standard projections on frontal and lateral views Comparison was made with the immediate postoperative examination

Guépar

Position of prosthesis cement surrounding the stems and presence of operative fractures were registered on the standard projections in lateral and frontal views The maximum width of the radiolucent zones around the bone cement in the presence of infection and/or fracture were registered in all roentgen exposures during the observation time In the rest of the material the width of the zone was registered one year after operation Scalloping and periosteal reactions were looked for in all examinations

Marmor

FTP angle measurement was made on the same basis as at the preoperative examination Based on standard frontal and lateral projections the angle of the tibial components in relation to the longitudinal axes of tibia was measured Fracture or buckling of the indicator wire was noted as a sign of loosening of the prosthesis The radiolucent zone under the tibial component was measured at the last examination By comparing the first postoperative examination and the examination at follow-up changes in the position of prosthetic components were noted The position of the femoral component in relation to the tibial plates was assessed

Classification of cartilage reduction and attrition in FT-joints preoperatively (Hagstedt 1974)

Narrowing of the articular space was defined as total cartilage thickness of 1-3 mm in the most destroyed compartment (equal to Ahlbäck class I) (Fig 1a)

Obliteration of the articular space was defined as cartilage thickness of less than 1 mm in the most destroyed compartment, but no certain destruction of subchondral bone (equal to Ahlbäck class II) (Fig 1b)

Attrition of bone was defined as changed configuration of the condyle of the tibia and/or femur This class also included knees with subluxation of the tibia (equal to Ahlbäck classes III-V) (Fig 1c-1d)

Classification of cartilage reduction and attrition in FP-joints

Normal cartilage was defined as at least 3 mm cartilage thickness and well-marked FP-joint spaces

Cartilage reduction was defined as cartilage thickness of 0-3 mm and well-marked FP-joint spaces

Attrition was defined as not detectable or a pathological configuration of the joint line This group included cases with lateralization or medialization of the patella

Measurements of varus and valgus deviations

The longitudinal axes of the femur and tibia were marked on the frontal projections with varus-valgus provocation The lateral open angle between the longitudinal axes of the femur and tibia at weight-bearing was designated the FTP-angle (Femoro-tibial angle Provoked) (Fig 2) The FTP-angle was measured on varus and valgus provocation and the largest divergence from 174° was recorded
Hagstedt in a study of gonarthrosis indicated the normal variation for the FT-angle at 168-180° The difference between FTP-angle in varus and valgus provocation was calculated as a measurement of instability in the knee at weight-bearing
In the Marmor and Guépar material lateral subluxation of tibia was also registered when found to exceed 5 mm

The errors in angle registration were considerable because short films were used in part of the examinations and presence of flexion contractures

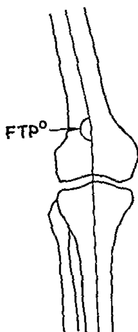


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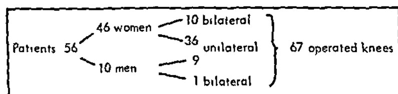
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III McINTOSH ARTHROPLASTY

MATERIAL AND METHODS

From 1967 through 1973 the McIntosh prosthesis was used in 59 patients for a total of 70 knees A follow-up was carried out during 1973-1974 two patients were examined in 1976 Three patients (3 knees) were excluded from the material one patient could not be traced two patients died from unrelated causes more than a year following surgery but prior to the follow-up According to case records the result were acceptable to the three patients The follow-up thus included 56 patients with 67 operated knees (Fig 3) The average age at operation was 54 years (26-74)

Fig 3



The observation time was on an average 3 3 years (1 0-6 0 years) Six patients had at follow-up been re-operated with another type of prosthesis (one bilateral) In these knees the observation time was calculated up to the time for re-operation

In more than half of the operated knees RA had been present for more than 10 years pre-operatively No patients with less than 2 years of RA were operated upon

Table 2
ESR preoperatively

ESR mm/h	0-25	25-65	66-150	Insufficient data
Knees	21	32	13	1

Previous treatment of the operated knee

Intra-articular cortisone In 28 knees between 1 and 10 cortisone injections were given and in 27 knees more than 10 injections Only 12 knees were never treated with intra-ticular cortisone

Statistical methods x)

Common parametric tests generally make certain assumptions about the population being tested and further assume at least interval level of measurement From a statistical point of view the important variables in this clinical investigation must be considered at not ordinal level of measurements and for that reason tests concerning association between variables, proportions and differences in location were accomplished by means of the following nonparametric procedures X^2-test, McNemar test, Wilcoxon Signed-Rank test and Kruskal-Wallis one-way test In applicable cases distribution-free multiple comparison techniques were used in judging treatments with a controlled level of significance (experimentwise error rate)

All processing of the data material was carried out by standard statistical software at the computer center of the University of Lund, in certain situations by means of specially developed programs for a minicomputer

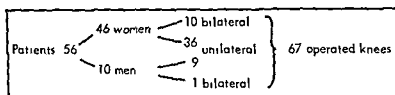
x) Aid in the statistical analysis is gratefully acknowledged to Mr Lars Ek

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Synovectomy Chemical synovectomy, using osmium acid, had been carried out in seven knees and a combination of chemical and surgical synovectomy in 22 Surgical synovectomy alone had been made in eight knees making a total of 37 chemical and/or surgical synovectomies, 25 of them between one and three years before arthroplasty

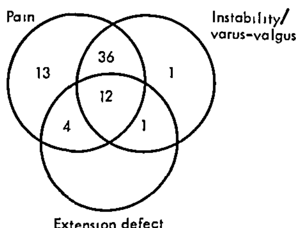
Capsulotomy was performed in six knees for correction of a flexion contracture

High tibial osteotomy was carried out in four knees to correct a valgus deformity

Indications for arthroplasty

The indications for the McIntosh arthroplasty were not uniform During the latter part of the period, the indications were more restricted as a consequence of increasing experience and introduction of new prosthetic alternatives The Venn-diagram (Fig 4) shows the clinical symptoms that motivated the operation

Fig 4
Clinical indication for McIntosh arthroplasty in 67 knees



Pain at weight-bearing or on walking less than 200 m

Instability ≧ 10° and/or

Varus
Valgus ≧ 10°

Extension defect >15°

Pain was found in all except two knees, operated because of instability and extreme valgus In 48 knees a combination of pain and considerable deformity and/or instability was found and 16 had pain and an extension defect Decreased flexion was not of such degree as to constitute an indication for arthroplasty

Contraindications With an extension defect of more than 30°, varus or valgus of more than 30° and subluxation of the tibia of more than 1 cm, it was not considered technically possible to construct a mobile yet stable and painfree joint by means of a McIntosh arthroplasty In these knees, arthrodesis was considered or the development of a better prosthesis was awaited

Operative technique

Two surgeons have operated on 64 knees and assisted at a further three (Fig 5a-b) The operation was performed under general or epidural anaesthesia through a medial parapatellar incision in a bloodless field In 20 cases during the first years the tibial tuberosity was detached to allow an easier approach to the knee joint In the remaining 47 knees the patella was dislocated laterally A synovectomy was performed In the presence of a flexion contracture a wedge was chiselled away from the tibia so that full extension became possible An adequately sized prosthesis was chosen to allow for circumferential cortical bearing and lateral stability

Bone cement as recommended by Yates (Brattström 1973) was used during 1971-1972 in 25 knees for attaching the prosthesis

Unicompartment arthroplasty was performed in 14 knees (Fig 6a-b) 11 of those in the lateral compartment If the tibial tuberosity was detached it was reattached with a screw or staple and a long leg plaster cast with an opening for the patella was applied following which the bloodless field was released Vacuum drainage was maintained for 24-48 hours postoperatively Prophylactic antibiotics and anticoagulation therapy were not used routinely

Postoperative treatment

During the first postoperative days quadriceps exercise was started and the patella was passively mobilized From the third day passive flexion and extension was started From the tenth day the patient was allowed to flex and extend actively and to walk with crutches After two weeks full weight-bearing was permitted and if flexion did not reach 90° four weeks after operation manipulation under anaesthesia was carried out If the tibial tuberosity was detached and reattached the patient was treated in the long leg plaster cast for two weeks and during the next four weeks increasing passive flexion and weight bearing with the use of a dorsal plaster slab was permitted If passive flexion did not reach 60° after three weeks open mobilization was performed This was carried out in 15 of 20 operations where the tibial tuberosity was detached and reattached

COMPLICATIONS

Operative complications and technical difficulties

In 25 of 67 operations technical difficulties or complications were encountered and modifications were adopted

Fracture of the tibia In one knee the cortical bone in the tibial condyle was fractured

Synovectomy Chemical synovectomy, using osmium acid, had been carried out in seven knees and a combination of chemical and surgical synovectomy in 22 Surgical synovectomy alone had been made in eight knees making a total of 37 chemical and/or surgical synovectomies, 25 of them between one and three years before arthroplasty

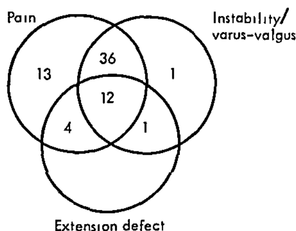
Capsulotomy was performed in six knees for correction of a flexion contracture

High tibial osteotomy was carried out in four knees to correct a valgus deformity

Indications for arthroplasty

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Fig 4
Clinical indication for McIntosh arthroplasty in 67 knees



Pain at weight-bearing or on walking less than 200 m
Instability $\geqq 10^{\circ}$ and/or
Varus $\geqq 10^{\circ}$
Valgus
Extension defect $> 15^{\circ}$

Pain was found in all except two knees, operated because of instability and extreme valgus In 48 knees a combination of pain and considerable deformity and/or instability was found and 16 had pain and an extension defect Decreased flexion was not of such degree as to constitute an indication for arthroplasty

Contraindications With an extension defect of more than 30°, varus or valgus of more than 30° and subluxation of the tibia of more than 1 cm, it was not considered technically possible to construct a mobile yet stable and painfree joint by means of a McIntosh arthroplasty In these knees, arthrodesis was considered or the development of a better prosthesis was awaited

Dislocation of the prothesis During manipulation under anaesthesia both plates were pressed down into the tibial condyles and a horizontal rotation of one of the plates occurred which resulted in a passive extension defect of 20°

Miscellaneous In one knee there was pain at weight-bearing Exploration of the knee revealed a fragment of cement posterior to the lateral prosthesis This was removed with relief of pain Another knee with pain on weight-bearing was explored and a number of subchondral cysts in the lateral femoral condyle were cleared of synovial membrane The cavity was filled with bone cement with relief of pain

Hospital stay The average duration was 48 days (18-126) In those patients where the tibial tuberosity had been detached the length of stay was increased by about half as much again

Late complications

Late complications occurred in eight knees

Patella dislocation In one knee the patella dislocated as a result of extreme valgus caused by compression of the lateral femoral condyle and a 2 cm lateralization of the tibia (Fig 9) A hinge prosthesis was subsequently inserted in this knee

Dislocation of the prosthesis In one knee a progressive sinking in of the lateral prosthesis and a lateralization of the tibia developed In one knee the lateral plate dislocated and at revision the plate was fixed with cement At a later date the medial plate dislocated to the lateral compartment (Fig 11) and a hinge prosthesis was eventually inserted

Collapse of the condyles Two knees developed an increasing collapse of the lateral femoral condyle This resulted in increasing valgus and instability In both knees, a high tibial osteotomy was carried out In one knee following a prosthesis in the lateral compartment an increasing collapse of the medial tibial condyle developed which led to a prosthesis being inserted in the medial compartment as well

Fractures One patient who was operated bilaterally in 1971 sustained a supracondylar fracture of the left femur without adequate trauma followed 12 month later by an identical fracture in the right femur (stress fractures) Both fractures healed uneventfully

when chiselling A fracture of the intercondylar eminence with a dislocation of the insertion of the anterior cruciate ligament was noted in seven knees Five of the fractures were left untreated In one the eminence was reattached with a wire and in one with a screw The screw perforated the posterior cortex of the tibia and because of the risk of erosion of the popliteal artery the screw was removed three weeks later

Cysts in the tibia In seven knees one of the tibial condyles was eroded by a subchondral cyst and extensive resection was necessary to achieve satisfactory bone support under the prosthesis, in three cases the cyst was filled with bone cement

Wrong size of prosthesis In three operations the thickest prosthesis was not adequate to compensate for the amount of destruction in the lateral condyle In one, the biggest plate was not large enough to obtain cortical bearing along the entire circumference and in another a prosthesis that was too thin was used as the correct size was not available

Patella dislocation In one knee with 10° of valgus preoperatively, the patella was found to be dislocated at operation and despite a medial transfer of the tibial tuberosity and a medial plication of the joint capsule, it remained dislocated

Extension defect In two knees full correction of an extension defect was not achieved and a 10° lag had to be accepted In one of these knees this was still present at the follow-up

Incongruity In one knee the arthroplasty was complicated by a lateral subluxation of the tibia and in another congruity between the femoral condyles and the prostheses was not obtained

Postoperative complications

Complications occurred in eight knees No thrombosis or embolism occurred in this series No patient died as a direct result of the operation

Complicated wound healing - superficial infection In four knees the wound failed to heal within four weeks In two a culture was negative and no antibiotics were given In the other two, the culture was positive (plasma coagulating staphylococcus, enterococcus and staph aureus) and antibiotics were used In these knees the wounds healed later without signs of deep infection

Dislocation of the patella In one knee there was crepitation at the FP-joint and pain *at extension* Clinically the patella was found subluxated laterally in the last 30° of extension

Dislocation of the prosthesis During manipulation under anaesthesia both plates were pressed down into the tibial condyles and a horizontal rotation of one of the plates occurred which resulted in a passive extension defect of 20°

Miscellaneous In one knee there was pain at weight-bearing Exploration of the knee revealed a fragment of cement posterior to the lateral prosthesis This was removed with relief of pain Another knee with pain on weight-bearing was explored and a number of subchondral cysts in the lateral femoral condyle were cleared of synovial membrane The cavity was filled with bone cement with relief of pain

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Fig 5a Normal position of prosthesis in frontal exposure

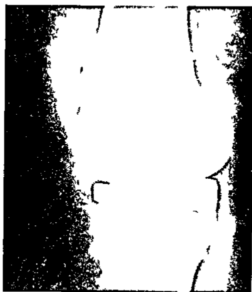


Fig 5b Normal position of prosthesis in lateral exposure



Fig 6a Hemiarthroplasty Postoperative examination



Fig 6b Destruction of contralateral compartment and medial femoral condyle 4 years postoperative

FOLLOW-UP EVALUATION

The seven parameters in Weinfeld s evaluation system (see page 9) formed the basis for evaluation of status preoperatively and at follow-up In the diagrams, the status at follow-up is marked by the position on the X-axes and the status preoperatively by the position on the Y-axes Positions along the oblique line indicate unchanged status, over the oblique line improved and below the oblique line worse

Table 3
Pain

Preop \ Follow-up (Points)	0	1	3	6	7	Sum
Follow-up sum	14	13	12	22	6	
7	6	8	6	12	4	36
6	4	4	3	9	2	22
3	3	1	2	1		7 Preop
1			1			1
0	1					1

For the patient pain was the primary indication for operation In 47 knee pain was less severe at follow-up than preoperatively unchanged in 16 and more severe in four

In 40 of the operated knees pain on walking less than 200 m was *present at follow-up*, a synovial swelling was found in seven of those Quadriceps power less than 100N was found in 32 and no less than 28 of them had pain when walking less than 200 m the correlation was significant (Chi^2 p = 0 0003)

Table 4
Use of support at walking

Preop \ Follow-up (Points)	0	1	2	4	Sum
Follow-up sum	12	21	9	25	
4	2	4	4	12	22
2	1	6	2	6	15 Preop
1	2	4	1	1	8
0	7	7	2	6	22



Fig 5a Normal position of prosthesis in frontal exposure

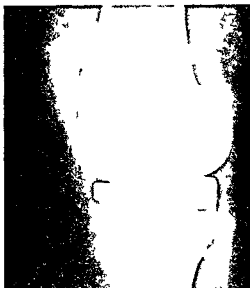


Fig 5b Normal position of prosthesis in lateral exposure



Fig 6a Hemiarthroplasty Postoperative examination



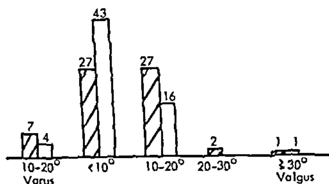
Fig 6b Destruction of contralateral compartment and medial femoral condyle 4 years postoperative

Table 7
Medial or lateral instability

Preop points	Follow-up 0	Follow-up 2	Follow-up 4	Sum
	37	20	4	
4	2	2	1	5
2	22	13	3	38
0	13	5		18

In 43 knees with preoperative lateral instability an improvement was achieved in 26 knees The instability was unchanged in 27 and increased in eight

Fig 7
Varus-valgus deformity at weight-bearing (clinical)



Preoperatively seven knees were in more than 10° of varus and 30 were in more than 10° of valgus At follow-up four knees were in varus in only one of them was the deformity present preoperatively In 16 knees 10-20° of valgus was found at follow-up and in one more than 30° The deformity developed postoperatively in only four knees
21 knees had no deformity preoperatively or at follow-up The deformity was corrected or diminished in 23 knees unchanged in 13 and increased in seven

The need for support at walking was reduced in 19 knees, unchanged in 25 and increased in 23 The failure to reduce the use of walking aids after knee arthroplasty was partly caused by pain at weight-bearing in other joints

Table 5

Extension defect

Preop points	Follow-up 47 (0 points)	Follow-up 15 (1 point)	Follow-up 4 (2 points)	Follow-up 0 (4 points)	Sum
4	1				1
2	12	3	1		16
1	16	9	3		28
0	18	3			21

Correction of preoperative extension defect was achieved in 29 of 45 knees, in three an improvement was noted In 28 knees the extension defect was unchanged and in six increased

Table 6

Flexion

Preop points	Follow-up 51 (0 points)	Follow-up 11 (1 point)	Follow-up 4 (3 points)	Sum
3	0	0	0	0
1	2	1	1	4
0	49	10	3	62

In Weinfeld s evaluation system the limit for acceptable flexion is set at 80° A limit of 100° would probably be better as this is the minimum requirement for negotiating stairs and for rising from chairs Flexion less than 80° was only present in four knees preoperatively and in none it was considered as an indication for arthroplasty Postoperatively flexion less than 80° was present in 15 knees The deterioration in flexion was significant

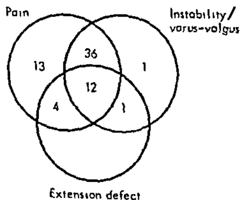
In classifying the knees at follow-up 12 were excellent 11 good 14 fair and 30 poor By simplifying the system into only two groups to facilitate statistical analysis of the material 23 knees were satisfactory (0-6 points) and 44 not satisfactory" (7-33 points)

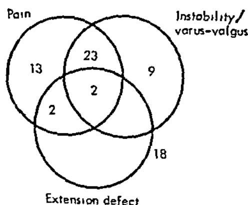
When comparing the status preoperatively with that at follow-up for the individual knee, excluding factors that could not be correlated because of insufficient data (quadriceps power preoperatively in 35 knees) it was noted that of the 44 knees with a not satisfactory result, 27 were improved 4 unchanged and 13 worse

Clinical indications for operation and results at follow-up

The clinical indications for operation and findings at follow-up were compared with similar parameters in Venn diagrams to illustrate the effect of arthroplasty

Fig 8





See Fig 4 for definitions

Preoperatively all knees were within the diagram at follow-up 18 knees lie outside the diagram those knees were without considerable clinical symptoms At follow-up there were 25 knees less with pain The combination extension defect and pain was reduced from 16 to 4 and the combination pain and instability and/or varus-valgus malposition was reduced from 48 to 25

Table 8

Quadriceps power

Preop points	Follow-up 0	Follow-up 1	Follow-up 2	Follow-up 4	Sum (Preop)
4	4	2	4	5	15
2	8	4	3		15
1					0
0	1				1
Follow-up sum	13	8	7	5	

Conclusion of results according to Weinfeld

For each of the seven parameters, the average point score preoperatively and at follow-up was calculated on the basis of the number of corresponding observations

Table 9

Score according to Weinfeld for the McIntosh material preoperatively and at follow-up

	Preoperatively	Follow-up	*Number of corresponding observations*	*Wilcoxon s SRT p*
Pain (0-7 points)	6 1	3 3	67	<0 01
Use of support at walking (0-4 points)	1 9	2 1	67	0 788
Extension defect (0-4 points)	1 0	0 3	66	<0 001
Flexion (0-6 points)	0 0	0 3	66	<0 05 (worse)
Medial or lateral instability (0-4 points)	1 4	0 8	61	<0 001
Varus-valgus on weight-bearing (0-4 points)	1 2	0 7	64	<0 05
Quadriceps power (0-4 points)	2 9	1 3	31	<0 001
Sum demerit points	14 5	8 8		

The average demerit points was 14 5 preoperatively and 8 8 at follow-up The score was thus reduced by 39 %

At follow-up reduction in pain and improvement of extension and lateral stability were *noted* Quadriceps power increased and varus or valgus on weight-bearing was reduced Against this, a moderate reduction of flexion and an increased need for support in walking was noted The reduction of flexion was less than the improvement of extension achieved Movement was therefore improved within the important range 0-80°

In classifying the knees at follow-up 12 were excellent 11 good 14 fair and 30 poor By simplifying the system into only two groups to facilitate statistical analysis of the material 23 knees were satisfactory (0-6 points) and 44 not satisfactory (7-33 points)

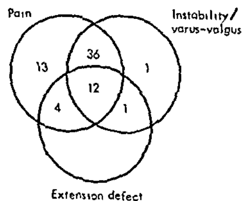
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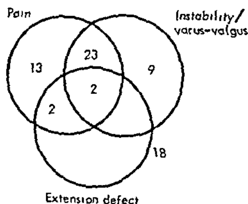
Fig 8

Clinical indications for operation



See Fig 4 for definitions

At follow-up



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EFFECT OF COMPLICATIONS ON FINAL RESULTS

(Satisfactory ' implies a Weinfeld score 0-6)

	No of knees	"Satisfactory '	"Not satisfactory"
Operative complications	25	5	20
Loosening of insertion of ant cruciate lig	7	1	6
Cysts in tibial condyle	7	1	6
Wrong size of prosthesis	5	-	5
Incongruence	2	-	2
Others	4	3	1
Postoperative complications (within two months)	8	2	6
Complicated wound healing	4	-	4
Dislocation of the patella	1	-	1
Dislocation of the prosthesis	1	-	1
Others	2	2	-
Late complications (after two months)	8	2	6
Supracondylar femur fracture	2	2	-
Dislocation of the patella	1	-	1
Dislocation of the prosthesis	2	-	2
Collapse of the condyles	3	-	3
Without complications	32	16	16

PREOPERATIVE ROENTGEN FINDINGS RELATED TO RESULTS

The numbers in parentheses after the number of knees in the tables show the number of not satisfactory ' results at follow-up to indicate the prognostic value

Table 10

Reduction of cartilage and attrition in FT-joints preoperatively

Narrowing of the articular space	5 (3)
Obliteration of the articular space	36 (21)
Attrition	22 (19)

(Insufficient data 4)

Result at follow-up were significantly poorer when attrition was present in one or both compartments (Chi^2 p = 0 024)

On the basis of the description of cartilage and bone attrition at operation, the material was divided into three grades according to the degree of destruction The gradings were chosen to enable direct comparison with the roentgen evaluation In 34 knees the clinical and roentgen assessment of the destruction was equal in 22 the destruction according to the operative findings was more pronounced compared to the roentgen examination and in seven the operative findings were less than was expected A significant correlation was found between the preoperative roentgen examination and the destruction as found at surgery (Chi^2 p = 0 029)

Table 11

Reduction of cartilage and attrition in FP-joints preoperatively

Normal height of cartilage > 3 mm	25 (15)
Reduction of cartilage 0-3 mm	26 (18)
Attrition	11 (9)

(Insufficient data 5)

With attrition in the FP-joint the final results were not satisfactory in 9 of 11 knees Significant correlation could not be proved

Table 12

FTP-angle on varus and valgus provocation preoperatively

>180°	10 (8)
180-168°	9 (1)
167-163°	20 (11)
<163°	17 (14)

(Insufficient data 11)

The best results at follow-up were in knees that preoperatively had an FTP-angle within the normal range, in 8 of 9 knees a "satisfactory' result was obtained

Even for knees in slight valgus, the result was quite acceptable At an FTP-angle between 163 and 180°, the result was significantly better at follow-up than in knees with an FTP-angle outside this range (Chi^2 p = 0 002)

Table 13

FTP-angle difference on varus and valgus provocation preoperatively

FTP-angle difference $<5°$	25 (13)
FTP-angle difference $\geq 5°$	32 (24)

(Inadequate data 10)

The FTP-angle difference was used as an indication of stability, even if there were considerable errors in method Poorer results were seen when the FTP-angle difference exceeded 5° (Chi^2 p = 0 07) Correlation between an FTP-angle difference and degree of cartilage reduction and attrition, as judged at operation or by analysis of the roentgen material preoperatively were found (Chi^2 p = 0 029 and Chi^2 p = 0 014) Those correlations that reflect what should be expected indicate that the method error on measuring the FTP-angle difference was not too important

ROENTGEN EXAMINATIONS AND RESULTS AT FOLLOW-UP

(Numbers in parentheses show the "not satisfactory results at follow-up)

Table 14

Attrition of femur condyles at follow-up

Only those with an obviously changed configuration of the femoral condyles or attrition were considered pathological

Normal configuration of femur condyles	43 (26)
Attrition or changed configuration	19 (15)

(Inadequate data 5)

The result was significantly poorer with attrition or changed configuration of the femoral condyles (Chi^2 p = 0 025)

Table 15
FTP-angle on varus and valgus provocation at follow-up

>180°	7 (5)
180-168°	26 (10)
167-163°	14 (12)
<163°	9 (8)

(Inadequate data 11)

The result was significantly better at follow-up when the FTP-angle in provocation was within the normal range (168-180°) (Chi^2 p = 0 0005)

Table 16
FTP-angle difference on varus and valgus provocation at follow-up

FTP-angle difference <5°	38 (18)
FTP-angle difference ≧5°	17 (16)

(Inadequate data 12)

At an FTP-angle difference exceeding 5° significantly poorer results were noticed (Chi^2 p = 0 001)

Table 17
Position of prosthesis at follow-up

Most pronounced displacement of the most dislocated prosthesis	
Lateral shift > 5 mm ≦ 10 mm	2 (2)
Lateral inclination > 5° ≦ 10°	7 (5)
Lateral inclination > 10° ≦ 20°	4 (3)
Anterior inclination > 5° ≦ 10°	6 (6)
Horizontal rotation more than 20°	1 (0)
Severe dislocation Inclination > 20° or lateral shift > 10 mm	10 (10)
Displacement	30 (26)
No displacement	34 (17)

(Inadequate data 3)

Only 4 of 30 knees with displacement of one or both prostheses had a *satisfactory*

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Patients opinion at follow-up

5 patients regretted having had the operation and 52 thought that they had benefited by the operation All knees that in the opinion of the patients were unacceptable had according to Weinfeld s point system a not satisfactory result The average score for this group was 15 points against 8 4 points for the others The reason for the patients disappointment in 13 knees was pain at rest or immediately at weight-bearing

To obtain a more precise idea of the patients impression of the result, the following four possibilities were suggested

Table 18

Almost normal	7
Improved	44
Unaltered	11
Deteriorated	5

Statistical correlation could be shown between the patients opinion and the evaluation result according to Weinfeld (Chi^2 p = 0 0003)

There was also a statistical correlation between patients opinion and pain at follow-up (Chi^2 p = 0 007)

ARA function class

All patients were graded both preoperatively and at follow-up according to the American Rheumatoid Arthritis Function Class System (Class I Manage without help to Class IV Totally dependent) This system was modified by dividing class III into subgroups a and b Patients in subgroup IIIa were considered stable enough to remain in this class with continued rheumatological treatment patients in subgroup IIIb (patients at risk) were likely to deteriorate to group IV unless surgery was undertaken Functional classification depends on the status of the entire locomotor system and can alter with disease activity as well as therapy during the observation time

result at follow-up When no dislocation was noted, 17 of 34 knees had a "satisfactory' result The 10 knees with severe dislocation had a not satisfactory" result at follow-up The result was significantly poorer when displacement was present (Chi^2 p = 0 002)

When comparing the position of the prosthesis at follow-up and immediately postoperatively, it was found that in 10 knees the displacement was present immediately postoperatively In 11 knees a slight displacement was present postoperatively but this increased during the observation time In nine knees, the position of the prosthesis was normal immediately postoperatively, but the increased displacement developed during the observation time The most usual displacement immediately postoperatively was an anterior inclination of one or both prostheses due to compensating for a preoperative extension defect

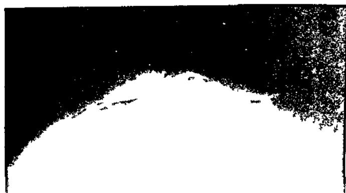


Fig 9 Postoperative subluxation of patella secondary to subluxation laterally and outward rotation of tibia



Fig 10 Pronounced displacement of the prosthesis and lateral subluxation of the tibia



Fig 11 Dislocation of the medial prosthesis to the lateral compartment

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result at follow-up. When no dislocation was noted, 17 of 34 knees had a "satisfactory" result. The 10 knees with severe dislocation had a "not satisfactory" result at follow-up. The result was significantly poorer when displacement was present (Chi^2, p = 0.002).

When comparing the position of the prosthesis at follow-up and immediately postoperatively, it was found that in 10 knees the displacement was present immediately postoperatively. In 11 knees a slight displacement was present postoperatively but this increased during the observation time. In nine knees, the position of the prosthesis was normal immediately postoperatively but the increased displacement developed during the observation time. The most usual displacement immediately postoperatively was an anterior inclination of one or both prostheses due to compensating for a preoperative extension defect.



Fig. 9. Postoperative subluxation of patella secondary to subluxation laterally and outward rotation of tibia.



Fig. 10. Pronounced displacement of the prosthesis and lateral subluxation of the tibia.



Fig. 11. Dislocation of the medial prosthesis to the lateral compartment.

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Table 19

ARA	Preoperatively	Follow-up
II	3	7
IIIa	18	22
IIIb (risk)	30	22
IV	13	13

(Insufficient data 3)

Improved 21

Unchanged 33

Worse 10

The improvement was significant (Wilcoxon s SRT p = 0 029)

No significant change in the socio-economic situation as a result of arthroplasty in the knee was found, but it must be seen as most satisfactory that 55 of these very disabled patients still manage to live at home

DISCUSSION

McIntosh arthroplasty in the Lund material resulted in 23 knees (34 %) with satisfactory and 44 (66 %) with not satisfactory results, using the Weinfeld point system at follow-up after an observation period of, on average, 3 3 years On the basis of 10 published materials (Andersson et al 1973, Blum et al 1974, Conaty 1974, Hastings and Hewitson 1973, McIntosh and Hunter 1972 Jani and Morscher 1973, Jessop and Moor 1972 Neville and Martins 1972, Potter 1969, and Schorn et al 1977) the frequency of good or excellent results in a total of 553 knees in patients with rheumatoid arthritis can be calculated at 57 % (38-82 %) with average observation periods of 1 6-4 0 years To compare different populations with different evaluation systems is of doubtful value, however (Andersson 1972) Jani and Morscher (1973) (11 knees with observation period 3 8 years) and Potter (95 knees with observation period 3 years) evaluated their materials using the Weinfeld point system and found satisfactory results in 82 % and 56 % respectively By using the evaluation criteria as reported by Blum et al (1974) (51 knees followed for 1 6 years), only 16 % of the knees in the Lund material fulfilled the requirements for a good result Blum et al (1974), however, reported 43 % good result in their series The results of the Lund material thus seem to be inferior to other published works This might be due to population differences, but can also be caused by differences in indications and contra-indications to surgery, the operative technique and postoperative treatment However

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(1971) considered extreme osteoporosis a contraindication In the Lund material the degree of osteoporosis was not quantitatively measured, but where systemic cortisone therapy had been administered for some years preoperatively, results were no worse than in the rest of the material

Other involved joints

Hastings and Hewitson (1973) considered poor function in the hip and foot joints a contraindication In the Lund material at follow-up, pain was experienced by eight patients at weight-bearing in the ipsilateral hip and by 11 in the contralateral hip In all cases where pain in the hips at weight-bearing was present, the result of the knee arthroplasty was not satisfactory' at follow-up In this material, pain at weight-bearing in the foot joints did not affect the result of the arthroplasty In eight patients where arthrodesis in the contralateral knee was performed before the knee arthroplasty, the result of the arthroplasty in all cases was not satisfactory

Surgical approach

Most authors have recommended a medial parapatellar approach Hastings and Hewitson (1973) recommended a lateral approach because of diminished damage to lymph drainage Burrough et al (1973) and Jessop and Moor (1972) recommended the use of two parapatellar incisions when prostheses were inserted in both compartments In the Lund material a medial parapatellar incision was consistently used the wound failed to heal within four weeks in only four knees Detachment of the tibial tuberosity was recommended by McIntosh (1971) and Jessop and Moor (1972) in the presence of severe destruction of the knee Hastings and Hewitson (1973) divided the patella tendon instead, because osteoporosis made detachment of the tibial tuberosity a hazardous procedure Other authors found detachment of the tuberosity to be unnecessary In the Lund material, the tibial tuberosity was detached in 20 knees the operation was made technically easier by this approach, but convalescence was delayed because of the necessary postoperative immobilization and the high incidence of open mobilization In spite of normal wound healing, absence of infection and a final result that did not differ from the rest of the material, there was a 50 % increase in the time spent in hospital

Operative procedure

Neville and Martins (1972) found that synovectomy was contraindicated because of decreased postoperative mobility after synovectomy McIntosh (1971) found that a synovitis often became inactive after arthroplasty and that synovectomy was indicated only in very active cases Most other authors have consistently performed a synovectomy at arthroplasty In the Lund material, synovectomy was consistently carried out The operat

"time was hardly increased and the partial denervation of the joint (Kellgren and Samuel 1950) may have been an advantage during mobilization

Opinions seem to differ considerably concerning management when pronounced destruction was found in the FP-joints Most authors mentioned that patellectomy should be avoided if possible The highest frequency of patellectomy was found in Murray s material (1967), 10 patellectomies in 20 arthroplasties Keever (1959) recommended patella prosthesis Potter (1969) recommended fascia lata plasty In the Lund material, only osteophytes were removed and erosions scraped Although reduction of cartilage or attrition was found in 37 of 62 knees considerable FP-joint problems were noted in only two knees postoperatively and then associated with patella subluxation In 9 of 11 knees with preoperative attrition in FP-joints results at follow-up were not satisfactory however

McIntosh (1971) recommended reshaping of the femoral condyles Potter (1969) and several others claimed the importance of chiselling away the bony ridge on the anterior part of the femoral condyles which develops when flexion contracture is present and the anterior edge of the tibia impinges on the femoral condyles Turner et al (1972) considered the use of a femoral mould prosthesis to be indicated if the main part of the destruction was localized to the femoral condyles In the Lund material hemiarthroplasty was not performed if the femoral condyles were severely deformed Because of the usually thin eburnated cortical covering of the femoral condyles the possibilities of remodelling the condyles were not considered realistic

Bone cement was not routinely used in any of the reports referred to in this discussion, but the use of cement for filling defects in the tibia is recommended Kates who developed a modification of the McIntosh prosthesis for fixation with bone cement recommended the consistent use of cement In the Lund material fixation with bone cement was only used in 25 knees with increasing frequency during the latter years Burrough et al (1973) McIntosh (1969) and Murray (1967) recommended insertion of a prosthesis into both compartments in rheumatoid arthritis regardless of the state of the least destroyed compartment Blum et al (1974) Conaty (1973) and Mowat et al (1973) recommended that a prosthesis be inserted only in one compartment if this achieves lateral stability and alignment In the Lund material unicompartment operation was performed in 14 knees which were less destroyed preoperatively than those in which a bicompartment arthroplasty was carried out At follow-up equal results in uni- and bicompartment operations were found

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Postoperative management

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possible, not two authors have recommended the same postoperative regime McIntosh (1971) used Jones s compression bandage and kept the knee extended for five days befor flexion was permitted Potter (1969) recommended flexion on the third day, but used a plaster cast to immobilize the knee at night for 8–12 weeks Weight-bearing was permitted by McIntosh (1971) after 5–7 days Potter (1969) considered that full weight-bearing was possible after three months In the Lund material wound healing was not a major problem From this point of view, passive flexion after three days had no harmful effects When cement is not used to fix the prosthesis, it seems reasonable to delay flexion and weight-bearing until fibrous retention of the prosthesis has developed At surgery, it was often observed that the prosthesis dislocated and that the anterior end of the prosthesis did elevate on flexing the knee With osteoporosis impaction of the prosthesis into spongious bone is also likely In this material a change in position of the pro sthesis from the first postoperative examination to follow-up was found in 20 knees The result at follow-up when there was displacement of the prosthesis was satisfactory' in only 4 of 30 knees, it was not known when displacement occurred, but some of the displacements might have been caused by the early mobilization

Manipulation under anaesthesia

McIntosh (1971) recommended manipulation under anaesthesia if flexion had not exceede 90° after two weeks cortisone was simultaneously injected into the knee In Potter s material (1969), manipulation under anaesthesia was carried out in one third of the operated knees Wnen the tibial tuberosity was detached, open manipulation after 2–3 weeks was considered an almost obligatory second stage and in this material it was done in 15 of 20 knees

Of 47 knees operated without detachment of the tibial tuberosity, manipulation under anaesthesia was done in only five knees In one of them, both prostheses were impacted into the tibia and a horizontal rotation of one of the prostheses developed with a marked impairment of mobility Early and active mobilization was instituted partly to avoid the risks involved with manipulation

Deep infection

In the 10 clinical materials previously referred to involving 553 RA knees, deep infection was reported in 24 (4 %) Only McIntosh and Hunter (1972) stated that they used irrigation with neomycine during surgery Systemic antibiotics did not seem to have been used by any of the authors In the Lund material, prophylactic antibiotics were not used and despite this, no instance of deep infection was noted The highest incidence of delayed wound healing or superficial infection was found in 10 of 51 knees in Blum s et al

material (1974) In the Lund material, complicated wound healing was found in four knees (6 %)

SUMMARY

67 knees in 59 patients with RA were operated with the McIntosh prosthesis from 1967 to 1973

At follow-up 3 3 years postoperatively an arbitrarily chosen degree of normalization of the knee 0-6 points according to Weinfeld s evaluation system equal to a satisfactory result was achieved in 23 of 67 knees Of 44 knees with seven or more points (not satisfactory) an improvement wa noted in 27 knees unchanged in four and worse in 13 The arthroplasty led to a reduction in pain, diminished extension defect and correction of lateral instability Quadriceps power was increased and deformity at weight-bearing reduced A moderate reduction of flexion was noted In 55 knees an improvement was achieved in the patients opinion in 16 the knee was unchanged or worse than preoperatively A moderate but significant improvement of ARA functional classification occurred

No fatal or life-threatening complications or deep infections were noted A not satisfactory result was found in connection with accidential loosening of the anterior cruciate ligament presence of large cysts in the tibia incongruency after insertion of the prosthesis and a prosthesis not large enough Postoperative complications in the form of dislocation of the patella dislocation of the prosthesis and collapse of the nonoperated compartment resulted in a high frequency of not satisfactory results Not satisfactory results at follow-up were also found when malposition of the prosthesis was present when valgus or varus deformity was present if the FTP-angle difference was $\geq 5^{\circ}$ and when destruction of the femoral condyles develop postoperatively

An improvement of results could obviously be achieved by stricter indications for the method Hemiarthroplasty gave poor results in patients who have been artrodesed in the opposite knee had pain in the hips at weight-bearing previous osteotomy or capsulotomy of the involved knee or who used a support to walk indoors preoperatively There only remained a small group of patients with moderate pathological changes in the knee where late synovectomy could be a realistic alternative Although the frequency of complications was acceptable at the time McIntosh arthroplasty has nothing to recommend its use as a rational prosthetic alternative

IV GUEPAR ARTHROPLASTY

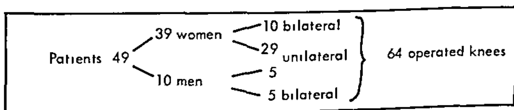
MATERIAL AND METHODS

The methods described in the introductory section p 7 were only modified with regard to the prosthetic design Postoperative roentgen examination at weight-bearing and provocation was not found to be of value because the mobility that developed on loosening of the prosthesis between cement and bone was so limited that the errors in FTP-angle measurements made the results unreliable The postoperative roentgen examination aimed at identification of prosthetic loosening and/or infection

To evaluate as early as possible the results of a Guépar arthroplasty, a preliminary postoperative examination was made after 12 months During 1976-1977, an additional follow-up was carried out if at least six months had elapsed since the preliminary examination In this way, 48 knees were examined on two occasions with on average 16 months (6-33) between examinations In knees with complicated wound healing or suspected deep infection, case records were checked, and where indicated, the patient was re-examined in June 1978

From 1972 through 1976, 49 patients, 39 women and 10 men, with RA were operated on with the Guépar prosthesis Five men and 10 women were operated bilaterally making a total of 64 prostheses

Fig 12



All operated knees were examined by the author and are included in the material
Observation time averaged 2 7 years (1 1-4 3)
Average age at operation 63 years (29-77), women 65 4 men 54 3

More than half of the patients had RA for more than 10 years before arthroplasty 53 knees were symptomatic for more than five years

Table 20

ESR preoperatively

ESP mm/h	0-25	26-65	66-150
Knees	15	34	15

Previous treatment of the operated knee

Intra-articular cortisone In 22 knees 1 to 10 cortisone injections were given and in 24 more than 10 injections 18 were never treated with intra-articular cortisone

Synovectomy Chemical synovectomy using osmium acid was carried out in seven knees and a combination of chemical and surgical synovectomy in 12 knees Surgical synovectomy alone was done in seven knees making a total of 26 chemical and/or surgical synovectomies

Capsulotomy was performed in four knees for correction of a flexion contracture

High tibial osteotomy was carried out in five knees two for correction of valgus, two for varus and one for correction of an extreme flexion contracture

McIntosh arthroplasty Eight previous McIntosh arthroplasties were converted to Guépar arthroplasties

Marmor arthroplasty Two previous Marmor arthroplasties were converted to Guépar arthroplasties because of collapse of the medial tibial condyle and loosening with displacement of the prosthesis

Indications for operation

The indications for Guépar arthroplasty were changed during 1972-1976 When the prosthesis was introduced in 1972 there was a group of patients with extremely destroyed knees in which a McIntosh prosthesis would not have been sufficient for reconstruction Because of the initially promising results following surgery the indications for Guépar arthroplasty were considerably widened and from 1973 through 1974 it was also used in knees which previously would have been operated with a McIntosh prosthesis Later through our own experiences and reported complications following hinge joint arthroplasty the indications were limited to the most severely destroyed knees

No maximum limit for degree of deformity subluxation between tibia and femur or extension defect was established it was possible by means of sufficient bone resection to align the tibia and femur and obtain full extension

IV GUEPAR ARTHROPLASTY

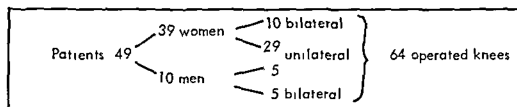
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Indications for operation

The indications for Guépar arthroplasty were changed during 1972-1976 When the prosthesis was introduced in 1972 there was a group of patients with extremely destroyed knees in which a McIntosh prosthesis would not have been sufficient for reconstruction Because of the initially promising results following surgery the indications for Guépar arthroplasty were considerably widened and from 1973 through 1974 it was also used in knees which previously would have been operated with a McIntosh prosthesis Later, through our own experiences and reported complications following hinge joint arthroplasty the indications were limited to the most severely destroyed knees

No maximum limit for degree of deformity subluxation between tibia and femur or extension defect was established it was possible by means of sufficient bone resection to align the tib a and femur and obtain full extension

IV. GUEPAR ARTHROPLASTY

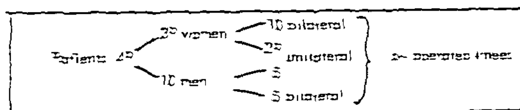
MATERIAL AND METHODS

The methods described in the introductory section p. 7 were only modified with regard to the prosthetic design. Postoperative roentgen examination at weight-bearing and provocation was not found to be of value because the mobility that developed on loosening of the prosthesis between cement and bone was so limited that the errors in [illegible] angle measurements made the results unreliable. The postoperative roentgen examination aimed at identification of prosthetic loosening and/or infection.

To evaluate as early as possible the results of a Guepar arthroplasty a preliminary postoperative examination was made after [illegible] months. During [illegible]–1977 an additional follow-up was carried out if at least six months had elapsed since the preliminary examination. In this way [illegible] knees were examined on two occasions with an average [illegible] months ([illegible]) between examinations. In knees with complicated wound healing or suspected deep infection case records were checked and where indicated the patient was re-examined in June [illegible].

From [illegible] through [illegible] [illegible] patients, 39 women and 10 men with RA were operated on with the Guepar prosthesis. Five men and 10 women were operated bilaterally making a total of [illegible] prostheses.

Fig. [illegible]



All operated knees were examined by the author and are included in the material.
Observation time averages [illegible] years ([illegible]).
Average age at operation [illegible] years ([illegible]), women [illegible], men [illegible].

More than half of the patients had RA for more than 10 years before arthroplasty. [illegible] knees were symptomatic for more than five years.

drained by a tube to prevent increasing pressure developing in the marrow cavity Solucortef 100 mg was administered intravenously and the patient was ventilated with pure oxygen These precautions were taken to prevent cardiopulmonary complications due to fat microembolism in the pulmonary capillaries (Olerud 1974) The femoral and tibial components were connected by the axle and the knee extended while the cement polymerized Because of lateral dislocation of the patella during surgery and preoperative lateral rotation deformity in many knees the tibia had a tendency to rotate outwards If the patella at this stage had a tendency to dislocate a medial plication was done A long leg plaster cast was applied and the bloodless field released Vacuum drainage was applied and maintained for 24-48 hours

Antibiotics Prophylactic treatment with cloxacillin 1 g x 4 and probenecid 1 g x 2 was started before surgery and continued postoperatively for 10 days in 52 of 64 operations In 12 operations no antibiotics were given before surgery or was discontinued earlier than 10 days because of secondary effects

Anticoagulation therapy was not used routinely

Postoperative treatment

The quadriceps was exercised from the first postoperative day and weight-bearing was permitted after 3-4 days The plaster cast was removed at two weeks and active flexion began If 90° flexion was not reached two weeks later manipulation under anaesthesia was performed in this material in 34 knees

COMPLICATIONS

Operative complications and technical difficulties

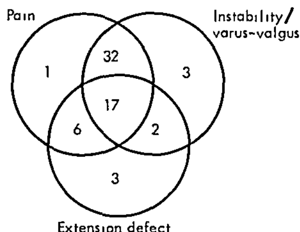
In 34 of 64 operations no technical difficulties or complications were encountered The technique was modified or complications noted in 30 operations In two operations two complications were noted

Patella dislocation In 17 knees lateralization of the patella occurred when the capsule was closed in six the tibial tuberosity was transferred medially in nine the lateral patella retinaculum was divided longitudinally (lateral release) and/or medial plication was performed In one knee a left-side prosthesis was used in the right knee thus maintaining slight varus and diminishing the tendency of the patella to dislocate

Fig 13

Clinical indication for Guépar arthroplasty in 64 knees

See Fig 4 for definition of subsets



Pain was found in 56 knees (Fig 13) In eight knees without pain, the main indication was instability and/or deformity in five and in three, an extension defect exceeding 30° 54 knees were unstable and/or in varus or valgus exceeding 10° In 28 knees there was an extension defect exceeding 15° Decreased flexion was not of such degree as to constitute an indication

Contraindications

Arthroplasty was not performed if there was a known focus of infection

Operative technique

One surgeon performed 51 operations and eight others performed 13 operations The operation was performed in a bloodless field under general or epidural anaesthesia A medial parapatellar incision was used and a synovectomy was carried out The collateral and cruciate ligaments were divided and the distal 15 mm of the femoral condyles resected so that the resected surface made a lateral open angle to the longitudinal axis of the femur of approximately 83° The posterior aspect of the femoral condyles and the inferior part of the patella groove were removed The proximal tibia was resected at a right angle to the longitudinal axis making the total resection of femur and tibia approximately 18 mm or more for correction of flexion contractures The position of the patella in relation to the depression on the femoral component was checked and if the patella dislocated laterally a lateral release was performed and if necessary the tibial tuberosity was transferred medially When inserting the cement the marrow cavities were

In three infection with purulent secretion local redness, swelling and tenderness were present Culture in two cases showed staph aureus and in one E coli The infections healed with antibiotic therapy after 8, 26 and 28 weeks but antibiotics were continued for three months one year and two years, respectively

Table 21
Predisposing factors for complicated wound healing

	Complicated wound healing (13)	Normal wound healing (51)
Patella dislocation at surgery or postoperatively	8	13
Transfer of the tibial tuberosity	4	4
Previous knee operations	6	25
Cortisone preoperatively more than one year	5	25
No prophylactic antibiotics at surgery	2	10
Manipulation under anaesthesia	8	26

Analysis of possible reasons for complicated wound healing (Table 21) showed that transfer of the tibial tuberosity (Chi^2 p = 0 026) patella dislocation at surgery or postoperatively (Chi^2 p = 0 013) were significantly increased

Deep infection In one knee with uncomplicated wound healing the knee became painful swollen and warm one month after operation No culture was taken but because of the clinical picture treatment with antibiotics was continued for six months The patient died of unrelated disease one year after operation without signs of infection in the knee

Patella dislocation In two knees with a tendency to patella dislocation at surgery, dislocation occurred postoperatively although correction with lateral release and medial plication was performed at operation Both knees were reoperated with a new medial plication

Peroneal palsy occurred after three operations In one the nerve was explored at six weeks and was found intact All three completely recovered

Pressure necrosis over the achilles tendon In one knee a pressure sore developed in the skin over the achilles tendon The defect healed spontaneously

Femoral fractures During physiotherapy two weeks after manipulation under anaesthesia

Extension lag (relaxed patellar ligament) In four knees with preoperative flexion contracture and limited quadriceps amplitude, the patellar ligament was extremely slack after insertion of the prosthesis In two of the knees the tibial tuberosity was transferred 3 cm distally to prevent an extension lag

Fractures or perforations Perforation of the femur (2) or tibia (3) caused by reaming or at insertion of the prosthetic components occurred in five knees but did not cause any major weakening of the bone Prolonged immobilization was not necessary and mobilization followed the normal routine In one knee after a previous high tibial osteotomy, the medial tibial condyle was fractured and the tibia rotated 25° laterally when the prosthesis was cemented

Loss of substance in tibial condyles Severe destruction of the tibial condyles because of subchondral cysts was found in three knees Most of the resection therefore was of the tibia In one knee the loss of bone in the tibia was caused by a total collapse of the medial tibial condyle following a failed Marmor arthroplasty

Wrong prosthesis In one knee with extreme varus preoperatively, a right knee prosthesis was inserted in the left knee due to an error in labelling following sterilization Most of the varus was however corrected and the prosthesis was therefore accepted

Postoperative complications

General complications occurred in four patients and local complications in 21 knees

General complications Respiratory complications developed in three patients within the first week after the operation lung embolus in one, pneumonia in two The patients made an uneventful recovery following conventional therapy In one case, a toxicodermi with fever developed caused by a previously unknown allergy against the prophylactic antibiotic

Complicated wound healing - superficial infection In 13 knees, the wound failed to heal within four weeks In one a necrosis measuring 7 x 2 cm healed without surgery after six months Several cultures were negative, but the surrounding tissue was red and warm In four a defect of 0 5-2 cm with a serous secretion and negative culture was present In one, blisters developed around the incision and culture showed β-streptococcus In four, secretion continued from the wound for 4-8 weeks and positive culture was found (anaerobic streptococci, staph epidermidis (two knees) aerobacter) All organisms cultured are usually found in normal skin and no signs of clinical infection were present Antibiotic therapy was continued until the wound healed

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Femoral fractures During physio herapy two weeks after manipulation under anaesthesia

one patient experienced intense pain at the middle of the femur Roentgen examination showed a fracture of the femoral diaphysis level with the tip of the prosthetic stem This might have been due to an infraction during manipulation or a stress fracture The fracture healed in balanced traction in eight weeks

Duration of hospitalization The average time spent in the Department of Orthopaedics or Rheumatology was 45 days (8-180) When complicated wound healing was present, the duration was increased on an average by 44 %

Late complications

Complications registered later than two months after operation but within the observation time occurred in 21 knees

Patella dislocation In five knees, the patella dislocated on flexion, lateral to the trochlea on the femoral component (Fig 16a and b) In one knee, this dislocation caused pain on flexion and extension and a transfer of the tibial tuberosity was carried out This reoperation was complicated by a superficial infection

Fractures A femoral shaft fracture occurred after a fall at home in a patient with a known late infection and a more than six mm broad radiolucent zone around the cement and loosening of the prosthesis (Fig 17a and b), following immobilization the fracture healed without complications

Late infection Because of the importance of deep infection as a complication after hinge arthroplasty all knees with complicated wound healing or suspected deep infection, even when evident after the follow-up examination, were reviewed in June 1978 Evidence of late infection were found in 15 knees The observation time was on average 4 6 years (2 1-6 0)
Diagnosis of late infection was based on a combined assessment of local clinical symptoms such as pain, swelling, redness and warmth, fistula and skin necrosis, and general signs of infection such as fever leucocytosis ESR and CRP elevation and bacteriological findings Roentgen observations such as abnormal width and enlargement of radiolucent zones, scalloping and periosteal reaction were also considered Scintimetry with Sr^{85} was done in most cases of suspected infection

Appearance of late infection

Half of the late infections appeared within the first year after operation After the first year, the cumulative curve become quite straight and was still rising After five years, an additional infection was found and it seems reasonable to expect more in the future

Table 22
Initial manifestation of late infection

Dolor rubor calor (2-3 months)	2
Fistula (12-41 months)	5
Septic arthritis (4-52 months)	3
Increasing radiolucent zone + pain at weight-bearing (11-62 months)	5

Two of the three patients that developed septic arthritis died of sep is within one week despite intensive antibiotic therapy

Table 23
Result of culture

No culture	2	
Culture from wound or fistula	6	Anaerobic streptococci β-streptococci, staph aureus staph albus + coliform rods staph aureus + gramnegative rods clostridia
Aspiration of the knee	1	Negative
Fenestration of femur	1	Staph aureus
Operative tissue culture at reoperation (6 samples in each case)	5	3 none isolated in 5-6 of 6 samples 1 Propione bact acne in 4 of 6 samples 1 Streptococci in 5 of 6 samples

According to Lindberg (1978) infection should be proved by taking six *tissue samples* from the suspected area when no antibiotics have been administered for six weeks These requirements were fulfilled in only two knees in one propione bact acne was found in 4 of 6 samples and in the other β -streptococci was found in 5 of 6 samples *In one knee a fenestration* was done pus was present and culture showed staph aureus which was considered the causative organism

In six knees where no culture was made or no organism was *identified but* where the *patient was under treatment* with antibiotics when the culture material was *obtained* infection could have been *present* In six knees culture from the wound or *fistula showed* the abovementioned organisms which might have been the causative organism but contamination could not be excluded

one patient experienced intense pain at the middle of the femur Roentgen examination showed a fracture of the femoral diaphysis level with the tip of the prosthetic stem This might have been due to an infraction during manipulation or a stress fracture The fracture healed in balanced traction in eight weeks

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cement was chiselled away After synovectomy and removal of all non-viable tissue, a new prosthesis was inserted with cement containing gentamycin

Arthrodesis was carried out in one knee 61 months after the initial signs of infection Observation time was too short to decide whether osseous healing would be achieved (Fig 18a and b)

Amputation In one knee a fulminant septic arthritis developed within a few days 18 months after the arthroplasty The prosthesis was removed perfusion drainage instituted and intensive systemic antibiotic therapy started but septicaemia with toxic manifestations developed On vital indication, an above-knee amputation was performed The patient survived has a lower limp prosthesis and a total hip arthroplasty in the contralateral hip performed without complications

Status June 1978

Late infections were diagnosed in 15 knees in 13 patients Two patients had died of septicaemia One above-knee amputation had been carried out (vide supra) Four had been reoperated with a change of prosthesis and were without signs of present infection One of these four was still on antibiotics because of an infection in the other knee One knee had been arthrodesed One with a slowly progressive low virulent infection was due for a change of prosthesis Three had no signs of infection more than one year after discontinuing antibiotics One had a continuous infection in both knees and was on antibiotics

The bacteriological diagnosis was thus definitely established in only three knees In 12 knees infection might have been present, but the causative organism was not positively identified

Factors predisposing to deep infection

Complicated wound healing In four knees with late infection, wound healing was not established four weeks after operation Only one of them had a clinically superficial infection initially with a fistula in the tibial tuberosity area Fistulography and exploration failed to show any communication with the joint These four knees were treated with antibiotics for 2, 15, 17 and 48 months before the deep infection became manifest

Antibiotic prophylaxis was used in 52 knees Late infection developed in nine In 12 knees, no prophylactic antibiotics were administered before surgery or was ended because of secondary reactions Late infection developed in six Prophylactic antibiotics significantly reduced the frequency of late infection

Transfer of the tibial tuberosity In 5 of 15 knees with a late infection, the tuberosity had been transferred In 49 knees without late infection, the tuberosity was only transferred in three Transfer of the tuberosity significantly increased the frequency of late infection

Dislocation of the patella at surgery or postoperatively, previous knee operations and cortisone medication did not substantially predispose to late infection in this material

Treatment of late infection

Treatment with antibiotics Nine patients with 11 infected knees were treated with antibiotics from 6 to 60 months (average 27 months) Two patients with three infected knees were still under treatment with antibiotics These knees were almost painfree but the prostheses were clinically loose with instability, the patients condition precluded reoperation In three knees, antibiotic treatment was discontinued and more than 12 months had passed without signs of reinfection Because of progress of infection in spite of antibiotic treatment, five knees were reoperated

Change of prosthesis In four knees the prosthesis was removed in two, it was replaced with a new Guépar prosthesis, and in two with a Shier prosthesis The reoperations were done 16, 17, 37 and 42 months after infection became manifest The Shier prosthesis was chosen in two knees because the stems were longer than in the Guépar prosthesis When removing the infected prosthesis, a 1 cm wide groove was opened longitudinally in the femur and tibia until the tip of the cement was identified and through this channel all

three increased From the preliminary examination to follow-up, the need diminished in *nine* and increased in five When quadriceps power was less than 100N at follow-up, the need for support at walking significantly increased

Table 26
Extension defect

Preop \ Follow-up	0	1	2	4	Sum
4	4	3	1		8
2	19	1			20
1	14	2	1		17
0	14	4			18
Follow-up sum	51	10	2		

Arthroplasty reduced or eliminated the extension defect in 42 knees, left it unchanged in two and increased it in five From preliminary examination to follow-up it increased in nine and was reduced in three No correlation could be shown between extension defect at follow-up and decreased quadriceps power

Table 27
Flexion

Preop \ Follow-up	0	1	3	6	Sum
6		1			1
3	1	1			2
1	6	2	1		9
0	43	4	3	1	51
Follow-up sum	50	8	4	1	

Flexion less than 80° was found preoperatively in 12 knees Of these an improvement of flexion was found in nine Flexion less than 80° was found in 13 postoperatively Of these the flexion had been reduced in nine From the preliminary examination to follow-up flexion increased in six and was reduced in one

FOLLOW-UP EVALUATION

The seven parameters in Weinfeld s evaluation system (see page 9) formed the basis for the evaluation of status preoperatively and at follow-up

Table 24

Pain

Preop points	Follow-up 0	1	3	6	7	Sum
7	26	2	3	4	5	40
6	9	2	2	2		15
3						
1						
0	8					8
Sum (Follow-up)	43	4	5	6	5	

Pain at rest or immediately at weight-bearing was an important indication for operation in 55 knees 35 of them were painfree after operation and in 13 knees, pain was diminished In 16 knees pain on walking was present at follow-up From the preliminary examination to follow-up approximately 12 months after operation (48 knees examined) pain increased in eight knees and diminished in 10

An analysis of the reasons for pain at follow-up in 16 knees on less than 200 m walking showed a high incidence of tibial tuberosity transfer dislocation of the patella at surgery and postoperatively and complicated wound healing No increase in pain was found in relation to late infection However, no significance can be attached to these factors even though occurring more than twice as much in the group with pain

Table 25

Use of support at walking

Preop points	Follow-up 0	1	2	4	Sum
4	8	3	5	27	43
2		6	5	3	14
1					0
0	7				7
Sum (Follow-up)	15	9	10	30	

In 22 knees the need for support at walking was diminished, in 39 unchanged and in

In 40 knees with considerable varus (24 knees) or valgus (16 knees) preoperatively, the FT-angle on weight-bearing was corrected to 164-184° Only four knees had valgus of 10 to 20° at follow-up This was caused in three by the stems of the prostheses abutting against the lateral cortex and in one, by late infection with loosening and marked resorption around the bone cement

Table 29

Quadriceps power

Preop points \ Follow-up points	0	1	2	4	Sum
4	6	2	15	14	37
2	2	2	2	3	9
1					
0					
Sum	8	4	17	17	

The quadriceps power was improved in 27 of 46 knees but power exceeding 200N was reached in only eight The quadriceps power was registered at the preliminary examination approximately one year after the operation and at follow-up on average 16 months later A comparison of the quadriceps power on these two occasions showed an improvement in two knees no change in 25, and a reduction in 24 This reduction was significant (Wilcoxon s SRT $p < 0\,0001$) many patients on testing experienced considerable, deep and intensive pain which often continued for several hours afterwards

Conclusion of results according to Weinfeld

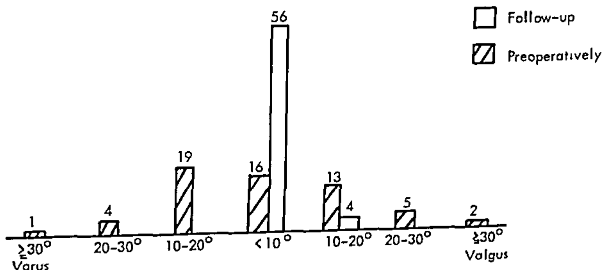
For each of the seven parameters the average point score preoperatively and at follow-up was calculated on the basis of the *number of observations*

Table 28
Medial or lateral instability

Preop \ Follow-up (Points)	0	2	4	Sum
Follow-up sum	58	2	1	
4	12			12
2	36		1	37
0	10	2		12

Arthroplasty eliminated preoperative instability in 48 of 49 knees At follow-up, instability exceeding 10° was found in three knees Of the 58 knees with less than 10° lateral or medial instability, a very limited (less than 5°) mobility was registered when the observation time exceeded two years This mobility, obviously present but not of a magnitude that permitted reliable measurement, could be caused by wear of the prostheses, or what is probably more relavant, mobility between cement and bone because of granulation tissue around the cement, which roentgenologically is visualized as a radiolucent zone From preliminary examination to follow-up, medial or lateral instability ≥10° developed in three knees Late infection with loosening of the prosthesis was the cause of instability in these knees

Fig 19
Varus-valgus deformity at weight-bearing (clinical)



In 40 knees with considerable varus (24 knees) or valgus (16 knees) preoperatively, the FT-angle on weight-bearing was corrected to 164-184° Only four knees had valgus of 10 to 20° at follow-up This was caused in three by the stems of the prostheses abutting against the lateral cortex and in one by late infection with loosening and marked resorption around the bone cement

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0					
Sum	8	4	17	17	

The quadriceps power was improved in 27 of 46 knees but power exceeding 200N was *reached in only eight* *The* quadriceps power was registered at the preliminary examination approximately one year after the operation and at *follow-up on average* 16 months later A comparison of the quadriceps power on these two occasions showed *an improvement* in two knees no change in 25 and a reduction in 24 This reduction was significant (Wilcoxon s SRT $p < 0\ 0001$) many patients on testing experienced considerable, deep and intensive pain, which often continued for several hours afterwards

Conclusion of results according to Weinfeld

For each of the seven parameters the average point score *preoperatively* and at follow-up was calculated on the basis of the number of observations

Table 30

Score according to Weinfeld for the Guépar material preoperatively, at the preliminary examination and at follow-up

	Pre-operatively	Preliminary examination (48)	Follow-up	Number of observations	Significant improvement (p)[x]
Pain (0-7 points)	5 9	1 5	1 3	63	<0 001
Use of support at walking (0-4 points)	3 1	2 6	2 3	64	<0 001
Extension defect (0-4 points)	1 4	0 1	0 2	63	<0 0001
Flexion (0-6 points)	0 3	0 6	0 4	63	0 523
Medial or lateral instability (0-4 points)	2 0	0 0	0 1	61	<0 0001
Varus-valgus at weight-bearing (0-4 points)	1 7	0 1	0 1	60	<0 0001
Quadriceps power (0-4 points)	3 5	1 4	2 3	46	<0 001
Sum demerit points	17 9	6 3	6 7		

[x] From preoperative to follow-up status

The average demerit points was 17 9 preoperatively against 6 7 at follow-up The score was thus reduced by 63 % Results at the preliminary examination of 48 knees approximately 12 months after operation was on average 6 3 points, which was 0 4 points better than average at the follow-up about 16 months later The deterioration was caused by decreased quadriceps power at follow-up On the basis of a comparison between average demerit points preoperatively and those at the three-year follow-up it can be concluded that the Guépar prosthesis has significantly reduced pain need for support at walking, extension defect, lateral instability varus-valgus deformity and quadriceps weakness Flexion has not been significantly reduced

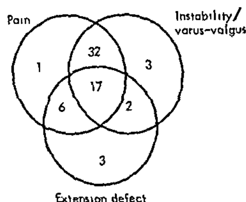
On the basis of Weinfeld s evaluation system, the score at follow-up in 10 knees was excellent, 20 good, 20 fair and 14 poor By simplifying the system into only two groups, 30 knees had a satisfactory ' result (0-6 points) and 34 a not satisfactory result (7-33 points) When comparing the status preoperatively and at follow-up for the individual knee with the exclusion of parameters that cannot be correlated because of inadequate data (quadriceps power preoperatively in 18 knees), it was found that 31 of the 34 knees with a not satisfactory result were improved, two unchanged, and one worse The considerable improvement reached even in this group could be confirmed by the patients own judgement, 29 knees improved, two unchanged and three worse

Clinical indication for operation and result at follow-up

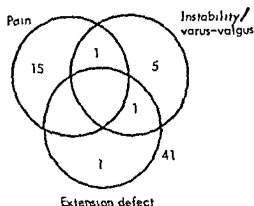
Clinical indications for operation and findings at follow-up were compared with similar parameters at follow-up in a Venn diagram

Fig 20
See Fig 4 for definition of subsets

Preoperative status



Follow-up status



Preoperatively 57 of 64 knees had a combination of *two or three* parameters At follow-up 41 knees were outside the diagram and *only two knees still* had a combination of two of the preoperative parameters Guépar *arthroplasty was less* effective in eliminating pain In three of the seven knees at follow-up with *lateral instability* and/or malposition in varus or valgus prosthetic loosening caused by *infection* was responsible

EFFECT OF COMPLICATIONS ON FINAL RESULTS

(Satisfactory implies a Weinfeld score 0-6)

	No of knees	Satisfactory	Not satisfactory
Operative complications	30	9	21
Dislocation of the patella	17	4	13
Active insufficiency of extensors	4	2	2
Fracture or perforation (tibia or femur)	7	-	7
Bony defects in tibial condyle	3	2	1
Wrong side prosthesis	1	1	-
No of complications (2 complications were noted *in 2 operations*)	32		

	No of knees	Satisfactory'	"Not satisfactory"
Postoperative complications (within two months)	21	9	12
Delayed wound healing	13	5	8
Dislocation of the patella	2	-	2
Peroneal palsy	3	1	2
Others	3	3	-
Late complications (after two months)	21	5	16
Late infection	15	3	12
Dislocation of the patella	5	2	3
Fracture of the femur	1	-	1
Without complications	16	10	6

PREOPERATIVE ROENTGEN FINDINGS RELATED TO RESULTS

The numbers in parentheses indicate 'not satisfactory' results at follow-up
Obliteration of the articular space was found in 16 knees and attrition of FT-joints in 48
In 19 of the knees, attrition was combined with lateral subluxation of tibia in relation to femur Results at follow-up were not related to the degree of observed destruction in FT-joints

Table 31

Reduction of cartilage and attrition in FP-joints

Height of cartilage > 3 mm	12 (6)
Reduction of cartilage 0-3 mm	23 (8)
Attrition	29 (20)

With attrition in the FP-joint the result was found significantly worse at follow-up (Chi^2 p = 0 021)

Table 32
FTP-angle on varus/valgus provocation

FTP >180°	18 (7)
FTP 180-168°	15 (8)
FTP 167-163°	6 (4)
FTP <163°	8 (6)

(Inadequate data 19)

Results at follow-up were better when the FTP-angle exceeded 180° and became gradually worse with decreasing FTP-angle (Chi^2 p = 0 031) Operative or postoperative dislocation of the patella was more common when the FTP-angle was <168° but there was no significant correlation

The FTP-angle difference on varus/valgus provocation were found to be without prognostic value

ROENTGEN EXAMINATION AND RESULTS AT FOLLOW-UP

The aim of the analysis of the postoperative roentgen material was to demonstrate signs of prosthetic loosening and infection The analysis was based on all existing roentgen material for each knee

Operative fractures and perforations

Fractures or perforations of the diaphysis at operation were demonstrated by the presence of extraosseous bone cement or the existence of loose fragments callus formation or periosteal reaction were late signs of operative fractures In six knees a perforation of the diaphysis was found two in the femur and four in the tibia All perforations were localized near the point of the stem and probably occurred on reaming or inserting the prosthesis There was no displacement in any of the fractures and healing was uneventful The result at follow-up was not satisfactory in all six knees with perforation although the prosthesis in only one knee was positioned with the point of the stem extraosseously (Fig 15)

Position of prosthesis

Direct contact of the prosthetic stem with cortical bone occurred in four knees in the femur 18 knees in the tibia and nine knees both proximally and distally The result at

follow-up seemed not to be related to the position of the prosthesis in the medullary cavity

Cement covering of the prosthetic stems

In 30 knees both stems were completely surrounded by cement and the results here were "satisfactory" in 16 In 34 knees one or both prosthetic stems were not completely surrounded by cement and results here were satisfactory in 14 The difference was not significant An indication of the importance of surrounding the prosthetic stems for maximum fixation was the fact that the radiolucent zone, measured 12 months after operation, significantly more often exceeded 1 mm when the stems were not completely surrounded This indicates that loosening of the prosthesis, although often of no major clinical importance, develops more rapidly in this group

Demarcation zone

The demarcation zone was defined as the radiolucent zone which often developed postoperatively around the cement and parts of the prostheses in contact with bone and which was limited by a condensation of osseous tissue (internal cortex) To regard a wide radiolucent zone as being pathological, knowledge of the normal demarcation zone in relation to time was essential It was therefore necessary to establish a normal material which excluded knees with deep infection, fracture or inadequate cementation of the prosthesis This subset was extracted by the exclusion of knees having the following criteria

1) Pain on walking less than 200 m
2) Inadequate cementation of one or both prosthetic stems
3) Operative or postoperative fractures of the femur or tibia
4) Knees with known ur suspected late infection

By this method 16 knees were extracted as a normal material All postoperative roentgen examinations for these knees were perused and the width of the zone was registered in relation to time following surgery

In the normal material the demarcation zone was less than 1 mm during the first four postoperative years, except in one knee where the demarcation zone was 1 5 mm after two years

Demarcation zone after one year In 58 knees the width of the demarcation zone registered at one year following surgery was between 1 and 2 mm in seven knees 2-4 mm in five knees and 4-6 mm in three knees 15 knees therefore had a demarcation zone after one year which exceeded normal expectations

Of the 15 knees with a demarcation zone exceeding 1 mm after one year the cement surrounding one or both prosthetic stems was inadequate in 12 Late infection was present in five of them and in three pain was present on walking less than 200 m In three with adequate cementation of the prosthesis no presence of late infection and no pain on weight-bearing the cause of a wide demarcation zone was obscure Significant correlation was found between a wide demarcation zone and inadequate cementation of prosthesis (Chi^2 $p = 0\ 017$)

Demarcation zone in late infection

In 15 knees with late infection the demarcation zone was measured in all roentgen examinations In eight the demarcation zone did not exceed 1 mm This means that a normal demarcation zone did not exclude infection In seven knees with a late infection the demarcation zone increased to more than 1 mm and in five of them progressive widening of the demarcation zone proved of practical value in establishing the diagnosis of infection

Scalloping - periosteal reaction

Scalloping means local widening of the radiolucent zone around the prosthesis (*Sjöstrand* 1974) In this material scalloping was seen in three knees 1 0-3 5 *years postoperatively* and late infection was present in all Periosteal reaction on a level with one of the points of prosthetic stems was seen in eight knees

Late infection was present in 6 of 11 knees with scalloping and/or periosteal reaction In these the demarcation zone exceeded 1 mm at examination one year postoperatively in three knees The role of infection in the development of periosteal reaction or scalloping was difficult to evaluate because 9 of the 11 knees with scalloping and/or periosteal reaction did not have sufficient cement surrounding on one or both prosthetic stems and therefore an inadequate cementation of the prosthesis may have accounted for the periosteal reaction A fracture was seen in only one knee with scalloping and a persistent periosteal reaction and a demarcation zone of more than 6 mm wide with deep infection (Fig 17a and b) In three knees a normal demarcation zone was found with no late infection or fractures present but a periosteal reaction level with the tip of the prosthetic stem In one of these knees the prosthesis was not sufficiently surrounded by cement and in the other two the tip of the stem was in contact with cortical bone the periosteal reaction was considered a stress phenomenon

Patients opinion at follow-up

Three patients stated that they would have refused operation had they known the outcome 61 patients were satisfied with the operation at the time of follow-up Of the

follow-up seemed not to be related to the position of the prosthesis in the medullary cavity

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DISCUSSION

Following Guépar arthroplasty in the Lund material results were satisfactory in 30 knees and not satisfactory in 34 at follow-up 2 7 years (1 0-4 3) after operation Clinical reports of Guépar arthroplasty in mixed materials of OA and RA were published by Deburge et al (1976) including 103 RA knees with an observation time exceeding 24 months Insall et al (1976) 24 RA knees with an observation time exceeding 24 months, Sneppen et al (1978) 35 RA knees with an observation time 3-26 months Witvoet et al (1974) have also published clinical results but the patient material seems to be partly identical with the series reported by Deburge et al (1976)

Insall et al (1976) and Witvoet et al (1974) reported two thirds excellent to good results Engelbrecht et al (1976) reported 77 % good results in 240 operations (OA + RA) with an average 33 months observation time Lettin et al (1978) using the Stanmore prosthesis in 100 knees (OA + RA) reported freedom from pain in 94 % and increased mobility in 67 % after more than two years

Arden (1973) reported 80 % good results in Shier arthroplasty after more than one year Following arthroplasty with the Walldius prosthesis, results between 67 % and 80 % were reported by Bain (1973) Freeman (1973) Walldius (1967) and Wilson and Venters (1976) Because of obvious differences in the evaluation system and population differences, a direct comparison of these results was not possible A discrepancy obviously exists between the results in the Lund material and reported frequencies of excellent and good results On the basis of the above clinical reports with a total of 1163 arthroplasties and the results in this material of 64 the intention was to discuss principle views of indication and complications

Indications

The main merit of the total constrained principle is the potential for reconstructing knees with extreme deformity and instability None of the works referred to indicated any maximum limits of destruction or instability Arden (1973) and Engelbrecht et al (1976) found that even ankylosed and previously arthrodesed knees could be operated with a hinge joint prosthesis if the extensor apparatus was intact In the Lund material the prognosis was poor when the FTP-angle preoperatively was less than 168° or attrition in FP-joints was found mainly caused by operative and postoperative FP-joint problems The minimum indication according to Witvoët et al (1974) and Bain (1975) was a destruction so pronounced that arthrodesis was the only alternative Walldius (1967) found maximum invalidity equal to life in a wheel-chair the main indication Of special interest is the minimum indication in materials where other prosthetic principles were used in the same period

three patients who regretted the operations one had an above-knee amputation, one was arthrodesed, and one had pain at rest and only 30° of flexion following surgery At follow-up, the patients opinion was

Table 33

Almost normal	20
Improved	39
Unchanged	2
Deteriorated	3

A statistical correlation existed between the patients opinion and the evaluation of results according to Weinfeld (Chi^2 p = 0 0005)

ARA functional classification

The ARA functional classification depends on the status of the entire locomotor system and can alter with the disease activity, therapy as well during the observation time can influence the functional grading, but it was still of interest to note whether knee arthroplasty had any influence

Table 34

ARA	Preoperatively	Follow-up
II	3	10
IIIa	13	18
IIIb (risk)	24	18
IV	24	18

Improved	25
Unchanged	32
Worse	7

The improvement was significant (Wilcoxon s SRT p 0 001) which was impressing when it was taken into account that these patients on average had 1 2 other joints in the lower extremities which were painful at weight-bearing The stability through hinge joint arthroplasty appears to be most beneficial to the patient in activities of daily living There was a significant correlation between ARA functional classification and results according to Weinfeld (Chi^2 p = 0 0005) However, the considerable functional gains reflected in an improvement in ARA functional classification following surgery did not result in any significant change in socio-economical conditions

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In the Lund material, indications were not uniform during the years when the prosthesis was used, but was always weighed against arthrodesis and against unconstrained arthroplasty The introduction of the hemiconstrained prostheses which will probably replace the constrained hinge prosthesis has made it difficult at present to categorically state the indications for the hinge joints On the basis of present experience, constrained or hemiconstrained prostheses should be used when the extension defect is greater than 20°, or malposition more than 20° Probably the most important indications are subluxation of the tibia, outward rotation of the tibia and insufficiency of the cruciate ligament which prevents congruency between prosthetic components in an unconstrained arthroplasty It is often an advantage to make the final decision during surgery when different prosthetic alternatives are possible

Complications

An analysis of the complications and those reported in the literature illustrate the risks and drawbacks of the constrained arthroplasty

General complications

Serious cardiopulmonary systemic or cerebrovascular complications following hinge joint arthroplasty were reported in several series Deburge et al (1976) in 292 Guépar arthroplasties had 14 serious hypotensions five with cardiac arrest three died lung embolism was noted in another five postoperative respiratory insufficiency in five and serious cerebrovascular problems developed in 12 Kenesi (1978) in 758 operations reported 18 deaths in connection with the operation and in another 20 cases life-threatening cardiopulmonary complications occurred within the first 24 hours following surgery Kenesi claimed that possible reasons for these complications were toxic reaction to

the lung parenchyma of nonpolymerized monomer, haemodynamic disturbances when releasing the bloodless field bleeding from the operation area and fat embolism In the Lund material lung embolism occurred in one case and pneumonia in two but fat embolism could not be excluded Serious complications were perhaps avoided by draining the marrow cavities with a catheter when the cement was introduced and the prosthesis inserted and by good anaesthesia Before inserting the prosthesis Solucortef 100 mg was given i v and the patient ventilated with pure oxygen

Dislocation of the patella

A Guépar Stanmore, St Georg and Walldius arthroplasty through the trochlea for articulation with the patella provide a hemiarthroplasty in the FP-joint In most published materials FP problems have been considerable Deburge et al (1976) reported FP-joint pain in 43 of 103 Guépar arthroplasties in 38 knees the patella was not central in relation to the trochlea of the prosthesis Insall et al (1976) found that pain was present when pressure was applied over the patella in 50 % of the cases and that alignment of the patella over the trochlea was often not achieved although lateral release was done at the arthroplasty Sneppen et al (1978) had subluxation or total dislocation of the patella in 32 of 50 cases but found that pain did not necessarily occur with subluxation Engelbrecht et al (1976) stated that FP-joint pain was the most usual explanation for residual pain which was found in 18 % of the cases at follow-up but that pain tolerance often developed after 1-2 years

FP-joint problems were considerable in the Lund material In 17 knees the patella at surgery showed a tendency to dislocate laterally The tibial tuberosity was transferred in six knees and a lateral release and/or medial capular plication was carried out in nine Despite this the patella dislocated later in seven knees and reoperation was necessary in three In the Lund material the frequency of dislocation increased slightly but not significantly by increasing valgus malposition preoperatively Lettin et al (1978) using the Stanmore prosthesis in 80 cases had no dislocations This can be due to the fact that the trochlea in this prosthesis is more anatomical in design and the patella is also reshaped using a template so that congruency in the femoro-patellar joint is achieved In the Walldius arthroplasty (Bain 1973 Blundell-Jones 1973 Freeman 1973 Walldius 1967 Wilson and Venters 1976) the presence of FP-joint pain or dislocation was not mentioned It might imply that the FP-joint problem was less important when using this prosthesis If cement was not used maximum outward rotation of the tibia was probably not often present In the Shier arthroplasty patellectomy is necessary Arden (1973) reported rupture of the patella ligament due to attrition against the prosthesis in 5 of 192 knees and other disadvantages of patellectomy such as delayed wound healing infection and biomechanical disadvantages must be considered The Guépar group (Alnot et al

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In the Lund material, indications were not uniform during the years when the prosthesis was used, but was always weighed against arthrodesis and against unconstrained arthroplasty The introduction of the hemiconstrained prostheses which will probably replace the constrained hinge prosthesis has made it difficult at present to categorically state the indications for the hinge joints On the basis of present experience, constrained or hemiconstrained prostheses should be used when the extension defect is greater than 20°, or malposition more than 20° Probably the most important indications are subluxation of the tibia, outward rotation of the tibia and insufficiency of the cruciate ligament which prevents congruency between prosthetic components in an unconstrained arthroplasty It is often an advantage to make the final decision during surgery when different prosthetic alternatives are possible

Complications

An analysis of the complications and those reported in the literature illustrate the risks and drawbacks of the constrained arthroplasty

General complications

Serious cardiopulmonary, systemic or cerebrovascular complications following hinge joint arthroplasty were reported in several series Deburge et al (1976) in 292 Guépar arthroplasties had 14 serious hypotensions, five with cardiac arrest, three died lung embolism was noted in another five, postoperative respiratory insufficiency in five and serious cerebrovascular problems developed in 12 Kenesi (1978) in 758 operations reported 18 deaths in connection with the operation and in another 20 cases life-threatening cardiopulmonary complications occurred within the first 24 hours following surgery Kenesi claimed that possible reasons for these complications were toxic reaction to

using Stanmore prosthesis In the Lund material deep infection was diagnosed in 16 knees (25 %) In one knee the infection was noted within the first two months and in 15 knees two months to five years following surgery A direct comparison of the reported rates might be misleading In the Lund material, for example, the diagnosis was attained without demands for bacteriological verification

Treatment of deep infection is extremely difficult when a cemented hinge prosthesis is used The implant is introduced deeply into two marrow cavities and the soft tissue covering is quite thin in the knee Resection of bone at arthroplasty and often destruction by the infection increases the problems of reconstruction An analysis of reported deep infections 7 5 % in approximately 1100 arthroplasties in the series previously referred to revealed that three patients died of septicaemia eight had above-knee amputations, in seven the prosthesis wa removed and in 45 knees an arthrodesis was attempted but union occurred in only 15 The prosthesis was changed in 11 knees with a relapse in four and healing in seven In 16 knees the infection was treated by systemic antibiotics in 13 the infection healed

Loosening

Fixation of the prosthesis in bone tissue is problematic and loosening of the prosthesis with instability deformity and pain at weight-bearing without signs of infection was shown in most published materials with an observation period exceeding two years Watson et al (1976) in 38 RA knees operated with a Shier prosthesis with an observation period of two to seven years found that pain and instability recurred within 18 months following surgery In the same period cystic radiolucencies and periosteal reactions were noted level with the tip of the stems as well as subsidence of the femoral component into the femur to an extent that limited flexion These X-ray changes indicated loosening of the femoral component Loosening with clinical symptoms were noted in 35 of 38 knees According to Watson et al (1976) prosthetic loosening with pain instability and gradual decreasing mobility was unavoidable after more than 18 months following surgery Arden (1973) reported only 7 % with loosening with an observation period exceeding 12 months in a Shier arthroplasty material of 192 knees Following Guépar arthroplasty Deburge et al (1976) reported loosening in 2 % (6 cases) in 292 arthroplasties Insall et al (1976) in 7 % (3 cases) in 45 arthroplasties In arthroplasty with Walldius prosthesis without the use of bone cement as recommended by Walldius (1967), Blundell-Jones (1973) reported that all prostheses were loose after two years

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1971) claimed that outward rotation of the tibia was the main reason for dislocation of the patella Sneppen et al (1978) claimed that damage to the vastus medialis, incorrect design of the 'trochlea", preoperative valgus and outward rotation of the tibia were all contributory causes In the author s opinion the tendency to dislocation was mainly due to faulty operative technique By introducing the axis while the bone cement in the tibia was still unpolymerized, the patella dislocated laterally and the knee flexed, a powerful outward rotation force was created on the tibia through the patellar ligament and the tibial part of the prosthesis was therefore in inward rotation in relation to the tibia itself Lettin et al (1978) used a lateral parapatellar incision and dislocated the patella medially, this prevented the outward rotation of the tibia

Wound healing

The highest incidence of wound healing complications was noted by Lettin et al (1978) in 100 Stanmore arthroplasties with delayed wound healing in 29 knees, skin necrosis in nine and a fistula in two Arden (1973) in Shier arthroplasties found wound healing complications in 17 % of 192 cases The required patellectomy was probably contributory Other reports previously referred to gave lower incidences of wound healing problems In the Lund material the wound failed to heal within four weeks in 13/64 knees despite immobilization in plaster Transfer of the tibial tuberosity and dislocation of the patella had an adverse effect on wound healing in the distal part of the incision, corresponding to the area of the tuberosity Deep infection later occurred in four cases

Wound healing complications are probably partly caused by the large volume of the implant and a relatively thin soft tissue covering They are less of a problem in unconstrained knee arthroplasty where although the approach to the joint, operation time and duration of bloodless field are the same, the implant is much smaller in size

Deep infection

Deep infection has been reported in hinge arthroplasty in all larger series and has been extremely difficult to treat The highest incidence of deep infection was found in Walldius material (1967), 14 % of deep infection in 67 knees, and in Blundell-Jones material (1973), 11 % deep infections in 120 operations The Walldius prosthesis is larger than others and was inserted without the use of bone cement which did not seem to be necessary for the high infection rates to occur Bain (1973), Freeman (1973) and Wilson and Venters (1976), who cemented the Walldius prosthesis reported infection rates of 5-10 % Deburge et al (1976) and Insall et al (1976) both reported 7 % deep infection using the Guépar prosthesis The lowest infection rate 2 % was reported by Engelbrecht et al (1976) using the St George prosthesis and Lettin et al (1978), 3 %

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walking The slight lateral instability was taken to indicate that rigid fixation of the prosthesis and cement to the bone tissue in one or both diaphyses was not maintained in most cases after two years In the same period when this slight instability developed, a significant decrease of the quadriceps power was noted On forceful contraction of the quadriceps, most patients experienced an intensive, deep pain The weakening of the quadriceps power was considered to be caused by pain inhibition, perhaps pain was caused by compression of granulation tissue in the space between cement and bone In the Lund material aseptic loosening was of quite limited consequence and the instability was without practical importance The effect of quadriceps weakening was difficult to judge, patients with hinge joint prostheses do not usually flex much in the stand-phase during walking and the demands on quadriceps power therefore are less than normal (van Hussen 1973) Adequate fixation of the prosthesis at operation appeared important The Lund material had a significantly increased frequency of a radiolucent zone larger than 1 mm after one year when one or both prosthetic stems were not properly surrounded by cement Also Insall et al (1976) noted a slight instability following Guépar arthroplasty, and explained it as being caused by wear of the axle in the prosthesis Mazas et al (1973) reported on wear of the prosthesis in vitro and by simple trigonometric calculations on the basis of these values, it does not seem probable that wear of the axle contributes to the lateral instability to any great extent Removal of the prosthesis after several years of function in active patients revealed only negligible wear of the axle

SUMMARY

64 knees in 49 patients with RA were operated with the Guépar prosthesis from 1972 through 1976 At follow-up 2 7 years after operation, an arbitrarily chosen degree of *normalization of the knee 0-6 points according* to Weinfeld s evaluation system equal to a satisfactory result, was attained in 30 of 64 operated knees Of 34 knees with a not satisfactory result, an improvement was noted in 31, unchanged in two and worse in one Arthroplasty resulted in reduction of pain, of need for support in walking of extension defect, of lateral instability and of the deformity at weight-bearing Quadriceps power was improved Flexion was not significantly diminished 59 knees were judged by the patients to be improved and five knees were unchanged or worse A significant improvement in ARA functional classification occurred

No serious general complication in relation to the operation was noted Considerable operative and postoperative FP joint problems were found, especially following preoperative valgus The result was significantly worse when dislocation of the patella existed Following perforation of the femoral or the tibial diaphyses at surgery, the result was

not satisfactory Although immobilized in plaster for two weeks postoperatively, there was delayed wound healing in 13 knees and four of them developed late infection

Late infection developed in 15 knees Infected cases were reviewed on average 4 6 years after operation they were followed after the end of the general observation period As a consequence of infection, two patients died of septicaemia and one had an above-knee amputation Five knees were reoperated four with a change of prosthesis and one arthrodesis At follow-up, the result was satisfactory in only three with late infection

Mechanical loosening of the prosthesis with slight lateral instability and reduction of quadriceps power was noted at follow-up when the observation period exceeded two years in most of the cases but did not affect the result of the arthroplasty

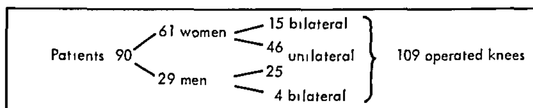
The main merit of the constrained principle is the almost unlimited capacity for correcting deformities and instability But a high frequency of patella dislocation complicated wound healing and late infection strongly argues against use of the method unless improvements in technique and infection prophylaxis are developed Dislocation of the patella can probably generally be prevented if outward rotation of the tibia is prevented by cementing in the tibial component before fixating the femoral component A reduced frequency of dislocation of the patella could also result in a lower frequency of delayed wound healing A reduction of the frequency of late infections could probably be achieved by improved hygiene and prophylactic antibiotics Since the introduction of a number of hemiconstrained prostheses the use of hinge joint prostheses can probably be restricted but observation periods thus far have been too short to establish rational indications

V MARMOR ARTHROPLASTY

MATERIAL AND METHODS

With the intention of evaluationg as early as possible the results following Marmor arthroplasty, a preliminary examination was made approximately 12 months after operation During 1977-1978, a second follow-up was made of all arthroplasties at least six months after the preliminary examination In this way, 96 knees were examined on two occasions with, on average, 15 months (6-32) between them from 1974 through 1977 Marmor arthroplasty was performed in 90 patients with RA in 61 women and 29 men, 4 men and 15 women were operated bilaterally making a total of 109 knees
Demiarthroplasty was performed in nine knees (5 lateral, 4 medial)

Fig 21



All operated knees were examined by the author and are included in the material

The observation time averaged 2 2 years (1 0-3 6) *One knee included in this series was* reoperated with a Guépar arthroplasty one month following surgery because of collapse of the medial compartment

Average age at operation was 59 years (24-79) with identical sex distribution

Most patients had had rheumatoid arthritis for more than 10 years before the arthroplasty Three-fourths of the knees were symptomatic for more than five years

Table 35
ESR preoperatively

ESR mm/h	0-25	26-65	66-150
Knees	13	58	38

Previous treatment of the operated knee

Intra articular cortisone In 56 knees 1-10 cortisone injections were given and in 37 knees more than 10 injections 16 knees were never treated with intra-articular cortisone

Synovectomy Chemical synovectomy using osmium acid was carried out in 12 knees and a combination of chemical and surgical synovectomy in 29 knees Surgical synovectomy alone was performed in 18 knees making a total of 59 chemical and/or surgical synovectomies

Capsulotomy was performed in three knees for correction of a flexion contracture

High tibial osteotomy was carried out in three knees two for correction of an extension defect and one for correction of an extension defect combined with valgus malposition

McIntosh arthroplasty Seven previous McIntosh arthroplasties were converted to Marmor arthroplasties

Indications for operations

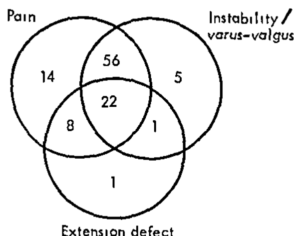
Indications in this material were not uniform In 1974 the Marmor prosthesis was used as an alternative to Guépar arthroplasty when the pathological changes were not too advanced In 1975 and 1976 the indications were widened to include also those knees with severe destruction because of an unacceptably high incidence of deep infections following Guépar arthroplasty In retrospect it is obvious that the indications for the Marmor arthroplasty at that period were in some cases unrealistic

After introduction of the Attenborough prosthesis in 1977 the Marmor prosthesis could again be reserved for knees requiring resurfacing and where deformities were correctible within the potentials of the prosthetic design

Fig 22

Clinical indications for Marmor arthroplasty in 107 knees

See Fig 4 for definition of subsets



Pain was present in 100 knees Of them, extension defects exceeding 15° were found in 30 and instability and/or malposition ≥10° in 78 In seven without pain preoperatively, the indication for operation was an extension defect and/or malposition Decreased flexion was in no instance of major importance as an indication for surgery

Contraindications

Synovectomy was preferred if joint surfaces were congruent, the deformity was moderate and the patient younger than 60 years In 1974 and 1975, the Guépar prosthesis was preferred if varus or valgus malposition or extension defect exceeded 20° Lateral subluxation of the tibia and pronounced outward rotation of the tibia which could not be corrected were relative contraindications

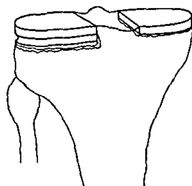


Fig 23 The medial prosthesis is countersunk in a trough according to the original technique The lateral prosthesis is placed with circumferential cortical support

Operative technique

Two surgeons operated two thirds of the knees and seven surgeons operated 1-15 knees each The operation was performed in a bloodless field under general or epidural anaesthesia A medial parapatellar incision was used and the patella was dislocated laterally A synovectomy was performed Resection of the posterior fifth of the femoral condyles allowed for the tibia plateaux to be chiselled at right angles to the longitudinal axis of the tibia In Marmor s (1973) description of the technique, the tibial plates are placed within corticalis, but we have considered it an advantage to have circumferential cortical support for the prosthesis (Fig 23) The position of the femoral prosthesis was determined by the need for congruency in relation to the tibial components and the need for sufficient support (Fig 24a and b) Prominence of the anterior part of the femoral component was when possible avoided because this might cause impingement on the patella during flexion (Fig 25a and b) The size of the femoral component was decided by the configuration of the condyle Before closure of the joint capsule it was ensured that the patella did not impinge on the anterior edge of the femoral component In this series patellectomy was performed in 12 knees for this reason After patellectomy mobilization was more difficult and in most cases persistant weakness of the quadriceps resulted A long-leg compression bandage was applied and vacuum drainage was maintained for 24-48 hours

Antibiotics Cloxacillin 1 g x 4 and probenecid 1 g x 2 was started before surgery and continued postoperatively for 10 days in 86 knees In 23 knees no antibiotics were given before surgery or were discontinued earlier than 10 days because of secondary effects

Anticoagulation therapy was not used routinely

Postoperative treatment

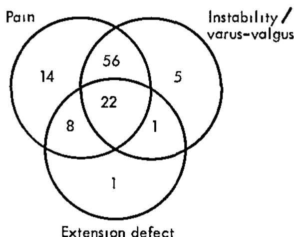
Quadriceps exercise started from the first postoperative day and as soon as the leg could be elevated against gravity weight-bearing with crutche was allowed

COMPLICATIONS

Operative complications and technical difficulties

In 66 of 109 operations no technical difficulties or complications were encountered In 43 operations the technique was modified or complications were noted Two complications were noted in 15 operations

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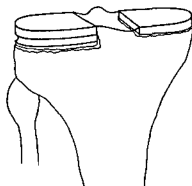


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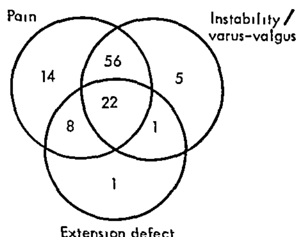
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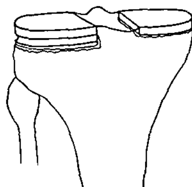


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after cementing in seven knees In six knees recementing was done in one the insufficient anchorage was accepted In three knees one of the tibial components was anchored in an unplanned inclination due to dislocation under the polymerization phase

Others In two knees extreme osteoporosis was found at operation Partial rupture of the patellar ligament while everting and laterally dislocating the patella occurred in one knee The rupture was repaired

Postoperative complications

In six operations general complications were noted and local complications in 35

General complications At operation, cardiac arrhythmia occurred in one case and subendocardial infarction in two cases Within the first postoperative week, one pneumonia, one Addison crisis in a cortisone treated patient and a deep vein thrombosis in the operated extremity were diagnosed In all cases of general complications the patients recovered without sequelae on conventional therapy No cases of embolism were detected No patient died as a result of the operation or during the hospital stay

Complicated wound healing - superficial infection In 11 knees the wound failed to heal within four weeks culture was negative in 10 The reason for delayed wound healing in five knees was skin necrosis which healed spontaneously in two and in three necessitated surgical intervention In four knees serous secretion was found which dried up spontaneously within three months Antibiotics were given in all knees with delayed wound healing but in no case was this prolonged more than six months Total wound rupture four days after operation occurred when one patient fell and hyperflexed the knee The wound was resutured after irrigation with antibiotics and healed uneventfully In one knee purulent secretion from the wound was found four weeks after operation and culture showed staph albus Revision was done at which a fragment of bone cement was found in the subcutaneous tissue The wound healed after resuturing but the knee was warm and tender and antibiotics were continued for six months

A slightly increased incidence of patellectomy and high incidence of previous operations in the involved knee were found when wound healing was complicated Systemic treatment with cortisone seemed not to be of importance The hospital stay was only increased by 1 7 days on an average when complicated wound healing was present

FP-joint pain In five knees there was pain and crepitation at the FP-joint Patellectomy was done in one and the knee became painfree but because of an extension defect quadriceps insufficiency and instability an arthrodesis was later performed In the other four knees the pain spontaneously diminished

Fracture of the tibia - resection of the tibial spine In five operations, the tibial spine was fractured, in three other operations, the spine was chiselled away because of collision against the anterior rim of the intercondyloid fossa In these eight knees, the insertion and thereby the function of the anterior cruciate ligament was destroyed

Fracture of the femur In one knee with pronounced rotatory instability, the medial femoral component was entrapped during flexion postero-medially against the tibial condyle During reduction the medial femoral condyle was fractured The fracture was retained in position by wire and healed uneventfully, although mobilization was long and troublesome

Cysts in the femur or tibia In seven knees large cysts were found subchondrally in the femoral or tibial condyles, necessitating larger resections or the filling of defects with cement

Impingement of the patella In 15 knees, impingement of the patella against the anterior edge of one or both femoral components occurred at operation This was caused by prominence of the femoral component in the patella sulcus and was often combined with a pathologically altered patella In 12 knees, a patellectomy was performed but in three the impingement was accepted with the expectation that the patella would be worn so that congruency would develop An extension defect was found at follow-up in 5 of 15 knees against 22 of 94 knees without FP-joint problems at operation The difference was not significant However, the quadriceps power was significantly reduced after patellectomy

Extension defect In seven knees with an extension defect between 15-35° preoperatively, the tibial plates were anteriorly inclined In four of these there was an extension defect exceeding 10° at follow-up

Congruence problems In seven knees, the surgeon considered the relationship between the tibial and femoral components as not being satisfactory, in five the tibia later subluxated laterally or posteriorly in relation to the femur, resulting in collapse of the arthroplasty Reoperation with an Attenborough prosthesis was performed in three knees and with a Guépar prosthesis in one Reoperation was planned in another

Insufficient correction of malposition Deformity in valgus was accepted in three knees to achieve lateral stability and full extension

Cementation problems One or both tibial components were found insufficiently anchored

after cementing in seven knees In six knees recementing was done in one the insufficient anchorage was accepted In three knees one of the tibial components was anchored in an unplanned inclination due to dislocation under the polymerization phase

Others In two knees extreme osteoporosis was found at operation Partial rupture of the patellar ligament while everting and laterally dislocating the patella occurred in one knee The rupture was repaired

Postoperative complications

In six operations general complications were noted and local complications in 35

General complications At operation, cardiac arrhythmia occurred in one case and subendocardial infarction in two ca es Within the first postoperative week one pneumonia, one Addison crisis in a cortisone treated patient and a deep vein thrombosis in the operated extremity were diagnosed In all cases of general complications, the patients recovered without sequelae on conventional therapy No cases of embolism were detected No patient died as a result of the operation or during the hospital stay

Complicated wound healing - superficial infection In 11 knees the wound failed to heal within four weeks culture was negative in 10 The reason for delayed wound healing in five knees was skin necrosis which healed spontaneously in two and in three necessitated surgical intervention In four knees serous secretion was found which dried up spontaneously within three months Antibiotics were given in all knees with delayed wound healing but in no case was this prolonged more than six months Total wound rupture four days after operation occurred when one patient fell and hyperflexed the knee The wound was resutured after irrigation with antibiotics and healed uneventfully In one knee purulent secretion from the wound was found four weeks after operation and culture showed staph albus Revision was done at which a fragment of bone cement was found in the subcutaneous tissue The wound healed after resuturing but the knee was warm and tender and antibiotics were continued for six months

A slightly increased incidence of patellectomy and high incidence of previous operations in the involved knee were found when wound healing was complicated Systemic treatment with cortisone seemed not to be of importance The hospital stay was only increased by 1 7 days on an average when complicated wound healing was present

FP-joint pain In five knees there was pain and crepitation at the FP-joint Patellectomy was done in one and the knee became painfree but because of an extension defect quadriceps insufficiency and instability an arthrodesis was la er performed In the other four knees the pain spontaneously diminished

Dislocation of prosthesis In one knee with persistent pain at weight-bearing, the joint was explored one month after operation and one of the femoral components was found loosened After recementing, the knee became painfree In the first month after operation, an increasing varus malposition was recognized in one knee associated with increasing pain at weight-bearing X-ray examination showed an increasing collapse of the medial compartment with loosening and dislocation of the tibial prosthesis A Guépar arthroplasty was performed

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Fracture One patient fell at home one month after arthroplasty and fractured the medial femoral condyle The fracture healed after eight weeks immobilization in a static orthosis

Others In four knees where patellectomy was performed in conjunction with the arthroplasty, an extension lag of 15-40° was found, in two of them the quadriceps power remained less than 50N at follow-up One knee had painful crepitation, which did not arise from the FP-joint A cineradiography showed that a collision between the lateral femoral prosthesis and the eminentia occurred during flexion This phenomenon seemed to be caused by a moderate lateralization of the tibia and was probably accentuated by a weakness of the quadriceps, which was secondary to an earlier patellectomy During physiotherapy, one knee suddenly locked in 90° of flexion At aspiration 50 ml serous sanguinous fluid were removed The locking has not recurred One knee had continuous moderate bleeding from the wound for two weeks, although coagulation tests were normal One 68-year-old cortisone-treated patient developed a postoperative haematoma in the thigh in the area where the bloodless field was applied The haematoma resorbed spontaneously but the quadriceps power remained extremely reduced During physiotherapy two weeks after operation, one patient fainted and fell, probably due to a subendocardial infarct and sustained a cervical hip fracture Because of necrosis of the head of the femur after primary nailing, a Moore arthroplasty was later performed

Hospital stay The average stay in hospital in the Orthopaedic or Rheumatological Department was 34 days (7-119)

Late complications

16 late complications were noted in 15 knees

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pain at weight-bearing A cineradiographic examination was made before reoperation This showed a mobile femoral component, which was recemented and the knee became painfree Six knees had a dislocation of one or both tibial components within the first postoperative year At arthroplasty, congruency between the tibial and femoral components was not achieved in this group All these knees were reoperated one had an arthrodesis, one a Guépar, and four an Attenborough

Collapse of condyles Because of pain at weight-bearing and increasing instability caused by destruction of the non-operated compartment following demi-arthroplasties, completion with a prosthesis in the lateral compartment was done in two knees and in the medial compartment in one Pain at weight-bearing was found in a further two knees which have not been reoperated

Fractures One patient fell at home one year after the arthroplasty sustaining a supracondylar femur fracture with minimum dislocation Reoperation with recementation of a dislocated medial tibial plate was planned when the fracture occurred but the patient preferred an arthrodesis

One patient noted pain at weight-bearing localized at the medial compartment Several roentgen examinations did not show anything abnormal Scintimetry with Sr^{85} six months after operation showed increased activity in the medial tibial condyle During the following months callus could be seen in the medial condyle on roentgen and the patient became painfree simultaneously with normalization of the scintimetry This knee illustrates the difficulties of diagnosing stress fractures in patients with rheumatoid arthritis



Fig 24a Normal position of prosthesis on frontal exposure



Fig 24b Normal position of prosthesis on lateral exposure

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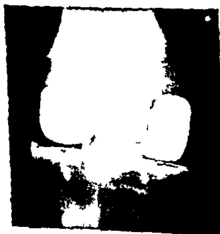


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16 late complications were noted in 15 knees

Dislocation of prosthesis One knee was explored six months after operation because of

From the patients point of view pain was the main indication for operation In this material pain was an important indication in 101 of 109 operations In 88 knees pain was eliminated or less severe at follow-up than preoperatively unchanged in 17 and more severe in four In five knees with pain at weight-bearing or at rest, reoperation with another prosthesis was done or was planned after the end of the observation time From the preliminary examination to follow-up pain diminished in 22 knees and increased in 12 In 28 knees with pain at walking less than 200 m at follow-up significant correlation was found to presence of exudate anterior drawer sign lateral instability weakness of the quadriceps and pain at weight-bearing in at least three other joints

Pain at rest or immediately at weight-bearing was found in 18 knees at follow-up An analysis of operative technical difficulties and the complications postoperatively during the observation time and the clinical status at follow-up showed that the main cause of pain was most probably the following

Dislocation of tibial component	6 knees
Incongruency between prosthetic components	4 knees
Instability (anterior drawer sign + lateral instability)	3 knees
FP joint dysfunction	3 knees
Extension lag + quadriceps-insufficiency	2 knees

Table 37

Use of support at walking

	Follow-up 44	21	25	19	Sum	
4	23	7	12	13	55	
2	6	7	6	1	20	Preop
1	5	4	1	1	11	
0	10	3	6	4	23	
Points	0	1	2	4		

In 60 knees the need for support at walking was reduced unchanged in 33 and increased in 16 From the preliminary examination to follow-up (on average 15 months) the need for support at walking was reduced in 16 knees and increased in 22 At quadriceps power less than 150N the need for support at walking was significantly increased The need for support at walking was significantly *increased* when an extension defect was present

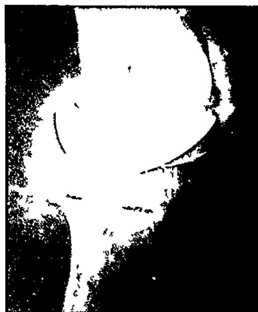


Fig 25a Impingement of patella on anterior edge of the femoral component wear defect of patella

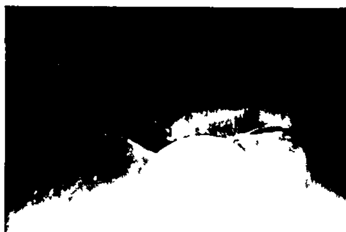


Fig 25b Same case axial exposure of the FP-joint wear defect of patella

Others In two knees, loose fragments of cement were identified by roentgen examination, apparently without major clinical symptoms

Late infection Late infection occurred in two knees (2 %) In one of these the infection was multifocal, due to septicaemia

FOLLOW-UP EVALUATION

The seven parameters in Weinfeld s evaluation system (see page 9) formed the basis for the evaluation of status preoperatively and at follow-up

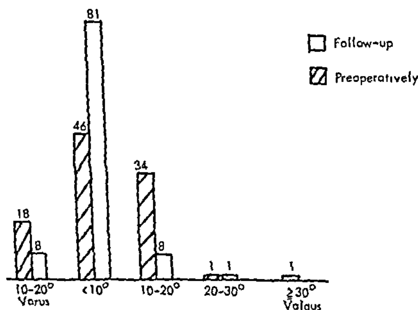
Table 36
Pain

Preop \ Follow-up	0	1	3	6	7	Sum (Preop)
Sum (Follow-up)	73	8	10	11	7	
7	41	2	6	5	5	59
6	23	3	3	6	1	36
3	3	1	1		1	6
1	1					1
0	5	2				7

Points 0 1 3 6 7

Preoperative instability was eliminated in 39 of 94 knees and reduced in four In nine knees instability developed in preoperatively stable knees in three it increased At follow-up instability >10° was found in 41 knees From the preliminary examination to follow up instability was significantly increased A high incidence of loosening of the prosthesis and altered position could explain this development The importance of medial or lateral instability might be increased by being found correlated to the presence of an anterior drawer sign (Chi^2 p 0 0001)

Fig 26
Varus-valgus at weight-bearing (clinical)



Preoperatively 18 knees had a varus malposition of more than 10° 13 were corrected but in three previously normal knees a varus malposition developed Of 35 knees with a valgus malposition ≥10° preoperatively correction was achieved in 25, reduction in one and increased valgus malposition developed in three knees There was a significant correlation between the degree of varus and valgus malposition and the degree of cartilage reduction and bone attrition noted at operation From the preliminary examination to follow-up a reduction of malposition was found in five knees and an increase in 12

Table 38
Extension defect

Preop points	Follow-up 0	Follow-up 1	Follow-up 2	Follow-up 4	Sum
Follow-up	82	22	5		
4	2	1	1		4
2	16	9	4		29
1	36	11	0		47
0	28	1	0		29

A preoperative extension defect was corrected by arthroplasty in 54 of 80 knees, reduced in a further 11 knees, unchanged in 43 and increased in one From the preliminary examination to follow-up, it was eliminated in 10, reduced in two, developed in 10 and increased in three

Table 39
Flexion

Preop points	Follow-up 0	Follow-up 1	Follow-up 3	Sum
Follow-up	104	4	1	
3		1		1
1	4			4
0	100	3	1	104

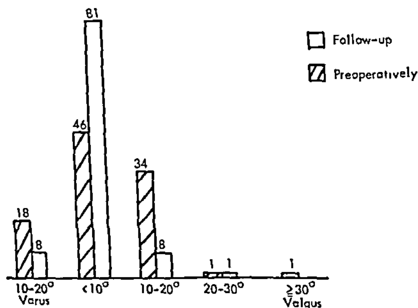
Flexion less than 80° was found preoperatively in five knees and at follow-up of these flexion exceeding 80° was found in four and an improvement in one In five knees, flexion less than 80° was found at follow-up From the preliminary examination to follow-up, flexion increased in seven knees and was reduced in two

Table 40
Medial or lateral instability

Preop points	Follow-up 0	Follow-up 2	Follow-up 4	Sum
Follow-up	59	36	5	
4	1	4	1	6
2	38	24	3	65
0	20	8	1	29

Preoperative instability was eliminated in 39 of 94 knees and reduced in four In nine knees instability developed in preoperatively stable knees in three it increased At follow-up, instability $>10^{\circ}$ was found in 41 knees From the preliminary examination to follow-up instability was significantly increased A high incidence of loosening of the prosthesis and altered position could explain this development The importance of medial or lateral instability might be increased by being found correlated to the presence of an anterior drawer sign (Chi^2 p 0 0001)

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Table 41

Quadriceps power

Preop \ Follow-up	25	17	18	13	Sum
4	10	9	13	9	41
2	11	6	4	3	24
1					
0	4	2	1	1	8
Points	0	1	2	4	

The quadriceps power was improved in 49 knees, unchanged in 17 and reduced in seven From the preliminary examination to follow-up, an improvement was found in 18 knees and a deterioration in 27 No correlation was found between quadriceps power and passive mobility or crepitation of the patella

Conclusion of results according to Weinfeld

For each of the seven parameters, the average point score preoperatively and at follow-up was calculated on the basis of the number of observations

Table 42

Score according to Weinfeld for the Marmor material preoperatively at the preliminary examination and at follow-up

	Pre-operatively	Preliminary examination (12 months after operation)	Follow-up	Number of observations	Significant improvement (p)x)
Pain (0-7 points)	5 9	1 5	1 4	109	<0 001
Use of support at walking (0-4 points)	2 5	1 2	1 2	109	<0 0001
Extension defect (0-4 points)	1 1	0 3	0 3	109	<0 001
Flexion (0-6 points)	0 1	0 1	0 1	109	0 425
Medial or lateral instability (0-4 points)	1 5	0 5	0 9	100	<0 0001
Varus-valgus at weight-bearing (0-4 points)	1 1	0 2	0 4	99	0 015
Quadriceps power (0-4 points)	3 2	1 3	1 4	63	<0 001
Sum demerit points	15 3	5 1	5 7		

Improved 9 6 points (63 %)

x) From preoperative to follow-up status

The average demerit points preoperatively was 15 3 against 5 7 at follow-up The score was thus reduced by 9 6 points (63 %) From the preliminary examination to follow-up 15 months later the average score according to Weinfeld was increased by 0 6 points The main reason for this deterioration was an increased incidence of lateral instability caused by loosening of the tibial components On the basis of a comparison between the average points for the seven parameters included in the evaluation system preoperatively and at follow up, it was found that with the Marmor arthroplasty there was a significant reduction of pain, of use of support at walking of extension defect of lateral instability, of varus and valgus deformity and of weakness of quadriceps Flexion was not significantly changed

In classing the knees at follow-up according to score based on Weinfeld s evaluation system 31 were excellent 45 good 13 fair and 20 poor By simplifying the system to include only two groups to facilitate the statistical analysis of the material 76 knees were satisfactory (0-6 points) and 33 not satisfactory (7-33 points)

When comparing the status preoperatively and at follow-up for the individual knee, excluding parameters that cannot be correlated because of inadequate data (quadriceps power preoperatively in 36 knees) it was found that of the 33 knees with a not satisfactory" result 21 were improved 2 unchanged and 10 worse Dislocation of the pros hesis was responsible in 6 of the 10 knees that were worse In the patients opinion an improvement was found in 17 knees 7 were unchanged and 9 had deteriorated

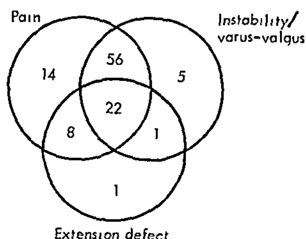
Clinical indications for operation and results at follow-up

Clinical indications for operation were compared with similar parameters in Venn diagrams to illustrate the effect of arthroplasty

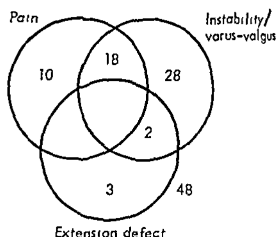
Fig 27

See Fig 4 for definition of subsets

Clinical indications



Follow-up



Preoperatively, all knees were in the diagram with 22 knees in the central subset At follow-up, 48 knees were removed from the diagram and none remained in the central subset

EFFECT OF COMPLICATIONS ON FINAL RESULTS

("Satisfactory implies a Weinfeld score 0-6)

	No of knees	Satisfactory	"Not satisfactory"
Operative complications (knees)	43	18	25
Accidental loosening of anterior cruciate lig	8	3	5
Fracture medial femoral condyle	1	1	-
Tibial cysts	7	5	2
Impingement of patella on femur component	15	10	5
Anterior inclination of tibial component	7	3	4
Incongruency	7	2	5
Lateral malposition not corrected	3	2	1
Insufficient cement initially	7	3	4
Osteoporosis	2	1	1
Patella ligament rupture	1	1	-
No of complications (2 complications were noted in 15 operations)	58		

	No of knees	Satisfactory	Not satis-factory
Postoperative complications (within two months)	35	28	7
Complicated wound healing	11	6	5
Patella impingement	5	4	1
Dislocation femoral component	1	1	-
Dislocation tibial component	1	-	1
Peroneal palsy	7	7	-
Fracture femoral condyle	1	1	-
Others	9	9	-
Late complications (after two months) (knees)	15	4	11
Late infections	2	-	2
Dislocation of prosthesis	7	1	6
Collapse of non-operated compartment	3	-	3
Loose fragments of cement	2	2	-
Condylar fractures	2	1	1
No of complications (2 complications were noted in one knee)	16		
Without complications	37	29	8

PREOPERATIVE ROENTGEN FINDINGS RELATED TO RESULTS

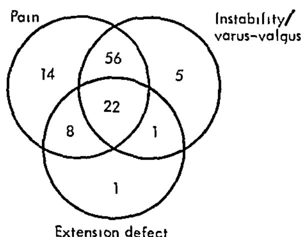
Narrowing of the articular space was found in six knees obliteration in 19 and attrition of FT-joints in 67 The articular space exceeded 3 mm in the best compartment in only 10 knees When attrition in one or both compartments was present a significant increase in the FTP-angle difference in provocation in varus and valgus was found $(Chi)^2$ $p =$ 0 015) In 13 knees attrition was combined with subluxation of tibia in relation to femur Results at follow-up were not related to the degree of observed destruction in the FT-joints

Reduction of cartilage and attrition in FP-joints, FTP-angle at varus and valgus provocation and FTP-angle difference at varus and valgus provocation were evaluated after same methods as in the McIntosh material but were found without prognostic value

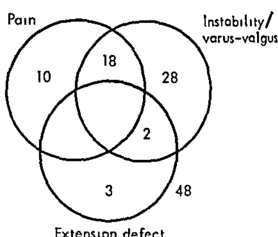
Fig 27

See Fig 4 for definition of subsets

Clinical indications



Follow-up



Preoperatively, all knees were in the diagram with 22 knees in the central subset At follow-up, 48 knees were removed from the diagram and none remained in the central subset

EFFECT OF COMPLICATIONS ON FINAL RESULTS

(Satisfactory implies a Weinfeld score 0-6)

	No of knees	Satisfactory	"Not satisfactory"
Operative complications (knees)	43	18	25
Accidental loosening of anterior cruciate lig	8	3	5
Fracture medial femoral condyle	1	1	-
Tibial cysts	7	5	2
Impingement of patella on femur component	15	10	5
Anterior inclination of tibial component	7	3	4
Incongruency	7	2	5
Lateral malposition not corrected	3	2	1
Insufficient cement initially	7	3	4
Osteoporosis	2	1	1
Patella ligament rupture	1	1	-
No of complications (2 complications were noted in 15 operations)	58		

	No of knees	"Satisfactory	Not satis-factory
Postoperative complications (within two months)	35	28	7
Complicated wound healing	11	6	5
Patella impingement	5	4	1
Dislocation femoral component	1	1	-
Dislocation tibial component	1	-	1
Peroneal palsy	7	7	-
Fracture femoral condyle	1	1	-
Others	9	9	-
Late complications (after two months) (knees)	15	4	11
Late infections	2	-	2
Dislocation of prosthesis	7	1	6
Collapse of non-operated compartment	3	-	3
Loose fragments of cement	2	2	-
Condylar fractures	2	1	1
No of complications (2 complications were noted in one knee)	16		
Without complications	37	29	8

PREOPERATIVE ROENTGEN FINDINGS RELATED TO RESULTS

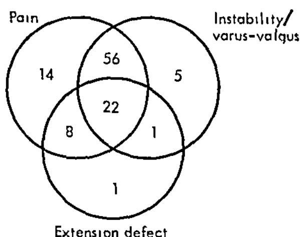
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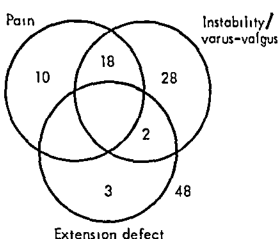
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Others	9	9	-
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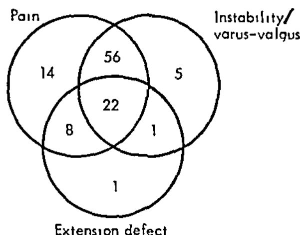
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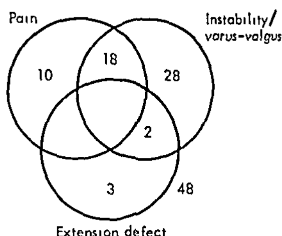
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No of complications (2 complications were noted in 15 operations)	58		

Change in position of the prosthesis in relation to prosthesis loosening

In the lateral compartment, a change in the position of the tibial component exceeding 5^{o} was found in 24 knees and in the medial compartment, in 33 cases (Fig 30) A significant correlation between loosening of prosthesis and change in position was found in the medial compartment (Chi^2 0 012) and in the lateral compartment (Chi^2 p = 0 0358) Treatment with systemic cortisone for more than one year and the length and weight of the patient had no influence on the incidence of change in position of the prosthesis

Radiolucent zone beneath the tibial prosthesis

In 11 knees where the zone exceeded 2 mm beneath one of the components the result was satisfactory in five knees (Fig 32) With increasing width of the zone there was a significant increased incidence of changed position of the prosthesis in the medial (Chi^2 p = 0 009) and lateral compartment (Chi^2 p = 0 022) This confirmed the supposition that the development of a radiological zone reflects mobility between bone and cement



Fig 28 Lateral subluxation of tibia eminentia collision of lateral femoral component, dislocation of medial femoral component



Fig 29 Fracture of indicator wires Buckling of the wire in medial compartment Abnormal camber angle of lateral femoral component

ROENTGEN EXAMINATION AND RESULTS AT FOLLOW-UP

The findings at the roentgen examination will be published in a separate paper (Andersen et al , unpublished data) and only results of relevance to the discussion in this chapter will be presented here

FTP-angle at varus and valgus provocation and FTP-angle difference at varus and valgus provocation were found without significant influence on the results at follow-up

Position of tibial components at follow-up

The usual malposition on a frontal view were medial inclination of the tibial components Malpositions were more usual in the medial compartment than in the lateral On the lateral view, the usual malposition was posterior inclination

Loosening of tibial components

The indicator wire is placed in direct contact with bone cement which anchors the component to the bone A break and/or buckling of the indicator wire is therefore a sign of loosening of the prosthesis (Fig 29)

Table 43

Thickness of components	Lateral component		Medial component	
	Stable	Loose	Stable	Loose
6 mm	9	10	17	23
9 mm	31	8	24	5
12 mm	16	2	9	2
15 mm-21 mm	7	1	1	3

(Inadequate data 22)

The indicator wire was broken in seven knees and buckled in 21 Breakage and buckling were combined in a further 26 knees In 21 knees, the lateral prosthesis was loose and in 33, the medial prosthesis The difference in frequency of loosening of medial and lateral components was significant (Chi^2 $p = 0\ 018$) In the medial compartment a 6 mm thick prosthesis was used in 40 knees Of these, 23 were loose It was more usual to use a 6 mm thick prosthesis in the medial compartment than in the lateral and the higher incidence of loosening in the medial compartment could partly be explained by this



Fig 31c Wear of lateral tibial prosthesis Indicator wire fractured and buckled



Fig 31d Wear of medial tibial component



Fig 32 Radiolucent zone 2 mm wide below lateral tibial component in a case with late infection No signs of loosening between component and cement

Summary of major pathological roentgen findings at follow-up

At operation the technical aim was to achieve a normal FT-angle positioning of the tibial components without major inclination stable anchorage of all components and central articulation of the femoral and tibial components

A Venn diagram indicates the correlation of major pathological findings at follow-up (Fig 33) Percentage of pathological findings are calculated in Table 44

There were no abnormal findings at the X-ray examination at follow-up in 20 knees at follow-up the result was satisfactory in 13 In 78 knees one or more of the pathological findings mentioned under A B C and D were found The incidence of not satisfactory results at follow-up varied from 22 to 42 % when at least one or two pathological findings were present The highest incidence of not satisfactory results (42 %) occurred in conjunction with an eccentric articulation between the femoral and tibial component (D) The results were not significantly worse than the results in the rest of the material (Chi^2 p = 0 069)



Fig 30a Collapse of lateral tibial condyle



Fig 30b Dislocation of lateral tibial component



Fig 31a Lateral subluxation of tibia Loosening of lateral tibial component, collapse of medial tibial condyle



Fig 31b Findings at reoperation

Table 45

Almost normal	39
Improved	51
Unchanged	10
Deteriorated	9

Statistical correlation was found between the patients opinion and the evaluation result according to Weinfeld (Chi^2 p 0 001) The patients opinion at follow-up was not correlated to disease activity as judged by the presence of pain in other joints A correlation between the patients opinion at the preliminary examination approximately 12 months after the operation and their opinion at follow-up on average 15 months later showed that 14 knees were considered improved, whereas 26 had deteriorated The patients were significantly less enthusiastic at follow-up than at the preliminary examination

ARA functional classification

All patients were classified preoperatively and at follow-up according to the American Rheumatoid Arthritis functional system This system was modified by dividing Class III into subgroups a and b Patients in subgroup IIIa were assessed as being able to remain in that class with continued treatment but patients in subgroup IIIb (patients at risk) were in danger of deteriorating to group IV unless radically treated

Table 46

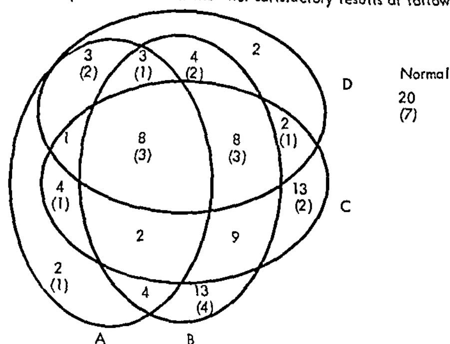
ARA	Preoperatively	Follow-up
II	3	19
IIIa	59	47
IIIb (risk)	31	28
IV	16	15

Improved	34
Unchanged	54
Worse	21

The improvement was significant (Wilcoxon s SRT p = 0 015) It must be remembered that in 65 knees pain at weight bearing was present in at least one other major joint in the lower extremities Correlation was also found between the result at follow-up according to Weinfeld and the ARA classification

The functional improvement reflected in an improved ARA classification did not lead to any significant change in socio-economic conditions

Fig 33 Major pathological roentgen findings at follow-up
(Numbers in parentheses show the "not satisfactory results at follow-up)



A FT-angle $< 168^\circ$ or $> 180^\circ$

B Inclination of the tibial component $> 10^\circ$

C Loosening of the tibial components

1) Change of inclination exceeding 10° or

2) Breakage or buckling of indicator wire

D Eccentric articulation between femoral and tibial components

(Inadequate data 11)

Table 44

Pathological findings

	A	B	C	D	AB	AC	AD	BC	BD	CD	Normal	Whole material
Number of knees	27	51	47	31	17	15	15	27	23	19	20	98
Percentage of 'not satisfactory' results at follow-up (%)	37	29	23	42	23	27	40	22	39	37	35	29

Patients opinion at follow-up

11 *patients stated that they would not have agreed to an operation had they known the final result Two had a 'satisfactory' and nine a 'not satisfactory'* result according to Weinfeld's point system *For a more precise idea of the patients impression of the result, the following four possibilities were suggested*

Table 45

Almost normal	39
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DISCUSSION

Following a Marmor arthroplasty in the Lund material there were 76 knees (70 %) with "satisfactory" results and 33 (30 %) with "not satisfactory" results after an observation period of 2 2 years (1 0-3 6)

The unconstrained total principle has only been in clinical use for about five years and therefore only a few series observed for more than two years have been published, none as far as is known restricted only to RA Marmor (1976a), who developed the modular prosthesis reported 88 % excellent to good results in a series of 124 operated OA + RA knees with observation time > 2 years Insall et al (1976) reported 64 % excellent to good results in a mixed RA + OA series of 42 knees with observation time > 2 years using the duocondylar prosthesis Cavendish et al (1978), Engelbrecht et al (1976) and Shaw et al (1978) reported 85-90 % excellent to good results using the Liverpool Mark II, St Georg Schlitten and Manchester prostheses in OA and RA The observation time exceeded two years in these series

Except for Insall et al (1976), who reported results worse than those presented in this series, other series seem to have only one-third to one-half as many 'not satisfactory" results than was found in the Lund material Differences in evaluation and populations could explain the discrepancy but indications, details in prosthetic design and operative technique could account for real difference in results

Loosening

Marmor (1976) reported loosening of the tibial components in 9 % of operated knees Most of them were overweight OA patients where 6 mm components were used In other reported series, the incidence of loosening was reported to be from 0-5 % (Engelbrecht et al 1976, Insall et al 1976, Laskin et al 1976, Shaw et al 1978)

In Lund, loosening of tibial components with considerable clinical symptoms was found in seven knees (6 5 %), but these were only a small fraction of the knees where roentgen at follow-up indicated loosening of tibial components In the medial compartment 39 % and in the lateral compartment 25 % of the prostheses were loose Loosening was significantly more common in the medial compartment than in the lateral probably because the 6 mm component was most often used medially

Change of position

Baldursson et al (1979) by roentgenstereophotogrammetry in one Marmor arthroplasty

without infection or clinical signs of prosthetic loosening showed a migration of the tibial component with tilting. Similar examinations have shown migration of acetabular cups in hip arthroplasties. This migration of polyethylene components was considered a general phenomenon and they considered the radiolucent zone found around implants to indicate small movements or a continuous migration of the prosthesis. Insall et al. (1976) found a radiolucent zone under the tibial components in about 50 % of knees and explain this finding as a result of insufficient anchorage and caused by the elastic properties of polyethylene.

In the Lund material, the angle between the longitudinal axes of the tibia and a plane through the indicator wire changed ≧ 5° in 132 of 187 tibial components examined. A radiolucent line ≧ 1 mm was seen under 95 of 162 components. A significant correlation was found between loosening and changed position and between the presence of a zone ≧ 1 mm and change of position.

In conclusion the present concept of unconstrained prostheses for practical use has considerable disadvantages. Wear of the tibial component results in a guiding through and the prosthesis therefore is no longer strictly unconstrained. The elastic properties of polyethylene favour loosening, which occurs early if thin components are used. Migration of polyethylene components seems to take place even if obvious loosening is not present. These observations are an indication for concern in the long-term use of this prosthetic principle. The wear could be reduced by using radiation improved polyethylene, as suggested by Grobbelaar et al. (1978) and the unfavourable effects of the elastic properties of polyethylene could perhaps be prevented by using metal interposed between polyethylene and bone cement (Goodfellow and Connor 1978) and thin tibial components should be avoided.

Contraindications

Contraindications vary in published clinical reports. An extension defect up to 20° was accepted by Engelbrecht et al. (1976), and Laskin et al. (1976). Cavendish et al. (1978) accepted up to 30°. Marmor (1976a) did not consider an extension defect of 60° in an ankylosed knee to be a contraindication. In the Lund series there was an extension defect exceeding 30° in four knees; full correction was obtained in only two of these. If an extension defect was not fully corrected, significantly worse results were found at follow-up and the need for support on walking was increased.

Engelbrecht et al. (1976) accepted varus or valgus up to 20°. Cavendish et al. (1978) and Marmor (1976a) used 30° as a limit. In the Lund series clinical malalignment up to

20° was accepted and the result at follow-up was not significantly influenced by the degree of malalignment found preoperatively

Engelbrecht et al (1976) and Shaw et al (1978) draw attention to ligamentary insufficiency in general Cavendish et al (1978) found posterior dislocation and Insall et al (1976) found rotation deformity or subluxation of special importance as contraindications In the Lund material preoperative lateral subluxation of the tibia was a relative contraindication

The anterior drawer sign has from a perusal of the literature not been mentioned as a contraindication Cavendish et al (1978) claimed that absence of the anterior cruciate ligament was not important In this series, the preoperative drawer sign was not associated with a significantly worse result (Chi^2 p = 0 079), probably because an anterior drawer sign is an unreliable indication of the absence of the anterior cruciate ligament in a destroyed rheumatoid knee At follow-up, a significantly worse result was found when the anterior drawer sign existed (Chi^2 p = 0 041) Correlation was also found between the anterior drawer sign and lateral instability at follow-up (Chi^2 $p < 0$ 0001), which implied that two-dimensional instability was often present In eight operations where the insertion of the anterior cruciate ligament was damaged, five had a not satisfactory" result at follow-up This finding also indicated the importance of internal stability

Lateral stability was important Only 2 of 39 knees with instability between 10 and 20° had an excellent result Five knees with instability more than 20° had a poor result Results were significantly worse when lateral instability was found at follow-up Loosening and altered position of the tibial components, from the preliminary examination to follow-up gave rise to lateral instability Stability acquired at operation was not always maintained In eight knees where unsatisfactory congruency between the femoral and the tibial components was obtained at surgery, a total collapse of the tibial condyles occurred in spite of cementation in the desired position These findings suggest the need for a review of the operative technique or the limits for indication

On the basis of reported contraindications in published clinical series and in this material, an unconstrained arthroplasty can only be recommended when an extension defect preoperatively is less than 20° and full extension can be achieved without anterior inclination of the tibial prosthesis Varus and valgus malposition should not exceed 20°, antero-posterior and lateral stability must be achieved at the operation and congruency between femoral and tibial components must be satisfactory It is often impossible to predict whether these demands can be fulfilled at operation and it is therefore mandatory to be able to choose another form of arthroplasty if necessary

The indications used in this series did not exceed recommendations of published works but on the other hand late synovectomy probably was preferred in many cases where others found arthroplasty suitable

Surgical technique

Marmor (1976a) considered it a major concept in design that the tibial components should be placed in an exactly reamed excavation within the cortical rim In this series an important modification was introduced (Fig 30) The tibial condyles were resected with an osteotome and the components were anchored with circumferential cortical support This modification partly inspired by the operative technique in McIntosh arthroplasty was technically simple and the cortical rim acting as a support was considered important for keeping the prosthesis permanently in position On roentgenological finding of loosening of one-third of the tibial components and change of position from the first postoperative examination to follow-up it was obvious that this technique did not fulfil the expectations of stable anchorage and the modification of the operative technique therefore was hardly motivated

Complications

Deep infection was reported by Marmor (1976a) in 7/126 cases (5 6 %) and also had a high incidence of wound healing problems (34 %) prophylactic antibiotics were not used None of the other series earlier referred to including the Lund series reported more than 0-2 % deep infections Although bone cement is used and the operation time is 1-2 hours deep infection has not been a quantitative problem

FP-joint Engelbrecht et al (1976) Insall et al (1976) and Sneppen et al (1978) considered FP-joint problems the most usual reason for pain at follow-up Sneppen et al claimed that dislocation of the patella was an important reason Marmor (1976b) reported that 21 % of 345 operated cases had retropatellar pain and in 6 % impingement was found Patellectomy was considered a possibility by Engelbrecht et al (1976) and Marmor (1976a) but it was regarded contraindicated by Insall et al (1976) because it did not prevent pain and usually caused quadriceps insufficiency

In the Lund material an impingement of the patella on the anterior edge of one or both femoral components was noted at operation in 15 knees and patellectomy was performed in 12 which resulted in significantly decreased quadriceps power and in five knees extension defects were present at follow-up Patellectomy was also found to predispose to complicated wound healing In five knees with painful crepitations postoperatively, patellectomy was performed in one and the pain diminished spontaneously in four

It can be concluded that FP-joint problems are considerable in this type of arthroplasty and are not connected to any special model of modular design Except for prevention of unnecessary prominence of the anterior edge of the femoral component, no acceptable treatment of this complication has been suggested

SUMMARY

109 knees in 90 patients with RA were operated with the Marmor prosthesis from 1974 through 1977 At follow-up 2 2 years (1 0-3 6) postoperatively, an arbitrarily chosen degree of normalization, 0-6 points according to Weinfeld s evaluation system - "satisfactory" results - was achieved in 76 of 109 knees (70 %) Of 33 knees with $\gtrsim$ 7 points - "not satisfactory" result - 21 were improved, 2 unchanged and 10 worse The arthroplasty resulted in a reduction of pain, diminished extension defect and lateral instability and correction of malposition at weight-bearing Quadriceps power increased and the need for support on walking was reduced Flexion was not significantly changed As judged by the patients 90 knees were improved and 19 unchanged or worse There was a significant improvement in ARA functional classification

Technical difficulties or operative complications occurred in 40 % of the operated knees Predisposing factors for 'not satisfactory' results were fracture of the tibial spine, cementation problems of the tibial components and when congruency between the femoral and tibial components were not achieved Impingement of the patella on the femoral components treated by patellectomy resulted in weakening of the quadriceps and increased the risk of complicated wound healing which was the most usual postoperative complication (10 %)

Impingement problems were also found postoperatively, but pain and crepitation diminished spontaneously in 4 of 5 knees Late infection developed in two knees

Loosening of components with clinical symptoms of a severity that required reoperations occurred in nine in two, the femoral component could be recemented, but in seven with loosening of the tibial component, arthrodesis or arthroplasty using another type of prosthesis was performed A review of the roentgen material showed that approximately one-third of inserted tibial components were loose and a change in position of the component had occurred These findings are probably precursors of future severe problems and are symptoms of failure of the unconstrained principle

The use of 6 mm components and the insertion of the tibial components with circumferential underlying cortical bone support, probably an advantage for preventing compression but insufficient for withstanding the shearing forces contributed to the high frequency of loosening in this material

The restricted indications for unconstrained arthroplasty are due to the imperfections of the available design and the requirement of sufficient soft tissue stability On the basis of present experience, unconstrained arthroplasty can be recommended if late synovectomy cannot be expected to result in an acceptable reduction of pain and permit walking Extension defect and malposition should not exceed 20° At surgery antero-posterior stability and lateral stability as well as congruency between the femoral and the tibial components must be achieved Because of the difficulties in predicting whether these requirements can be fulfilled other prosthetic alternative should always be available

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	McIntosh (67) Knees	Not satisfactory	p	Guépar (64) Knees	Not satisfactory	p	Marmor (109) Knees	Not satisfactory	p	Total material (240) Knees	Not satisfactory	p	Population difference Chi² p
Males	11	5	(-)	15	8	( )	33	11	(-)	59	24	(-)	(-)
Females	56	40		49	26		76	22		181	88		
Age at operation <60 years	52	32	( )	18	8	(-)	44	10	(-)	114	50	0 05	McIntosh younger
≧60 years	15	12		44	26		65	23		126	61		
Observation time <2 years	19	11	(-)	24	13	(-)	41	12	(-)	84	36	(-)	McIntosh longer than Guépar longer than Marmor
≧2 years	48	33		40	21		68	21		156	75		
Duration RA in general <5 years	24	15	(-)	11	5	(-)	24	7	(-)	59	27	(-)	Marmor longer duration 0 007
≧5 years	43	29		53	29		85	26		181	84		
Duration RA in the knee <10 years	31	15	0 006	20	10	(-)	28	11	0 014 (paradox)	79	36	(-)	Guépar longer duration 0 05
≧10 years	36	29		44	24		81	22		161	75		
Disease activity ESR preoperatively <35 mm/h	21	12	( )	21	13	(-)	28	9	(-)	70	34	(-)	(-)
≧35 mm/h	35	31		43	21		81	24		159	76		
ESR postoperatively <35 mm/h	18	9	(-)	23	14	(-)	32	11	(-)	73	34	(-)	(-)
≧35 mm/h	44	33		41	20		77	22		162	75		
Serology negative	25	16	(-)	12	7	(-)	41	11	(-)	78	34	(-)	(-)
positive	35	22		31	15		62	19		128	58		
Activity of disease in patients opinion: Less active	18	10		16	4		34	8		68	22	0 026	(-)
Same	31	21	(-)	24	14	0 028	31	8		86	43		
More active	17	17		24	16		44	17	(-)	85	45		

VI STATISTICAL ANALYSIS OF TOTAL MATERIAL AND SUBSETS

240 knees arthroplasties were performed at the Department of Orthopaedic Surgery, University Hospital of Lund from 1967 through 1976 This material was composed of three subsets

1) 67 knees operated with unconstrained hemi-arthroplasty (McIntosh)

2) 64 knees operated with constrained arthroplasty (Guépar)

3) 109 knees operated with unconstrained total arthroplasty (Marmor)

POPULATION DIFFERENCES AND EQUALITIES IN SUBSETS

In this material, all knees were similarly evaluated using identical parameters The three subsets were analysed for equalities and differences in population according to a variety of pre- and postoperative criteria, considered to have a potential influence on the results (Table 47) A Chi^2-test was performed for each criteria, if the p-value was less than 0 05, the subsets were judged significantly different The three subsets were all identical according to 15 criteria The McIntosh and Guépar subset were identical according to one criteria, the McIntosh and Marmor subset to nine criteria, and the Guépar and Marmor subset to five criteria Observation time was significantly different for all three subsets

<u>Population differences in subsets of major importance for comparison</u>

The observation period in the Marmor material was significantly shorter i e 2 2 years as opposed to 2 7 years in the Guépar material and 3 4 years in the McIntosh material

In the Guépar material, increased incidence was found of bony attrition at operation, possibly caused by a longer period of disease involvement in the involved knee Increased deformity such as extension defects and varus- and valgus malpositions, and decreased quadriceps power was noted in the Guépar subset Increased need for support on walking and the patient s lower functional classification according to the ARA system was primarily due to the condition of the involved knee because duration of general disease, ESR, serology, pain at weight-bearing in other joints and previous arthroplasties in other joints were identical in the three subsets As a consequence of the radicality in the Guépar arthroplasty significantly worse results were not shown in the light of these population differences but it does not exclude that worse results could have been expected if these patients had been totally unselected and operated with McIntosh or Marmor arthroplasty

Table 47

	McIntosh (67) Knees	McIntosh (67) Not satisfactory	McIntosh (67) p	Guépa (64) Knees	Guépa (64) Not satisfactory	Guépa (64) p	Marmor (109) Knees	Marmor (109) Not satisfactory	Marmor (109) p	Total material (240) Knees	Total material (240) Not satisfactory	Total material (240) p	Population difference Chi^2 p
Sex: Males	11	5	(-)	15	8	(-)	33	11	(-)	59	24	(-)	(-)
Sex: Females	56	40		49	26		76	22		181	88		
Age at operation: <60 years	52	32	(-)	18	8	(-)	44	10	(-)	114	50	0 05	McIntosh younger
Age at operation: ≥ 60 years	15	12		44	26		65	23		126	61		
Observation time: <2 years	19	11	(-)	24	13	(-)	41	12	( )	84	36	(-)	McIntosh longer than Guépar longer than Marmor
Observation time: ≥ 2 years	48	33		40	21		68	21		156	75		
Duration RA in general: <5 years	24	15	(-)	11	5	(-)	24	7	( )	59	27	(-)	Marmor longer duration 0 007
Duration RA in general: ≥ 5 years	43	29		53	29		85	26		181	84		
Duration RA in the knee: <10 years	31	15	0 006	20	10	(-)	28	11	0 014 (paradox)	79	36	(-)	Guépar longer duration 0 05
Duration RA in the knee: ≥ 10 years	36	29		44	24		81	22		161	75		
Disease activity — ESR preoperatively: <35 mm/h	21	12	( )	21	13	( )	28	9	( )	70	34	(-)	( )
ESR preoperatively: ≥ 35 mm/h	35	31		43	21		81	24		159	76		
ESR postoperatively: <35 mm/h	18	9	( )	23	14	(-)	32	11	( )	73	34	(-)	(-)
ESR postoperatively: ≥ 35 mm/h	44	33		41	20		77	22		162	75		
Serology: negative	25	16	(-)	12	7	(-)	41	11	(-)	78	34	(-)	(-)
Serology: positive	35	22		31	15		62	19		128	58		
Activity of disease in patients opinion: Less active	18	10		16	4		34	8		68	22		
Same	31	21	(-)	24	14	0 028	31	8		86	43	0 026	(-)
More active	17	17		24	16		44	17	(-)	85	45		

	McIntosh (67)			Guépar (64)			Marmor (109)			Total material (240)			Population difference
	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Chi^2 p
Previous treatment													
Cortisone systemic													
< 1 year	27	15	(-)	33	15	(-)	53	18	0 09	113	48	(-)	(-)
≧ 1 year	31	19		31	19		56	15		117	53		
Involved knee													
Cortisone intra-articular													
≤ 5 injections	32	19	(-)	34	15	0 089	55	16	(-)	121	50	(-)	(-)
> 5 injections	35	25		29	19		54	17		118	61		
Osmium acid intra-articular Yes	29	20	(-)	19	10	(-)	41	11	(-)	89	41	(-)	(-)
No	37	23		45	24		68	22		150	69		
Synovectomy Yes	26	16	(-)	17	7	(-)	40	12	(-)	73	35	(-)	
No	41	28		47	27		69	21		157	76		
Capsulotomy Yes	6	6	(-)	4	1	(-)	3	2	(-)	13	9	0 087	(-)
No	61	38		60	33		106	31		227	102		
Osteotomy Yes	4	4	(-)	5	1	(-)	3	2	(-)	12	7	(-)	
No	63	40		59	33		106	31		228	104		
Other joints (until follow-up)													
Bilateral knee arthroplasty (same type) Yes	22	12	(-)	30	18	(-)	44	12	(-)	96	42	(-)	
No	45	32		34	16		65	21		144	69		
Arthroplasty other knee (other type) Yes	2	2	(-)	6	2	(-)	11	6	(-)	19	10	(-)	(-)
No	65	42		58	32		98	27		221	101		
Arthrodesis other knee Yes	8	8	0 027	2	1	(-)	3	0	(-)	13	9	(-)	
No	59	36		2	33		106	33		27	102		

		McIntosh (67) Knees	McIntosh (67) Not satisfactory	McIntosh (67) p	Guépar (64) Knees	Guépar (64) Not satisfactory	Guépar (64) p	Marmor (109) Knees	Marmor (109) Not satisfactory	Marmor (109) p	Total material (240) Knees	Total material (240) Not satisfactory	Total material (240) p	Population difference Chi^2 p
Extension defect	≤15°	49	33	( )	35	24	0 007 (paradox)	76	23	(-)	160	80	(-)	Guépar more often extension defect 0 044
	≥15°	17	10		29	10		33	10		79	30		
Flexion	≥80°	62	39	(-)	51	27	(-)	104	31	(-)	217	77	0 006	Guépar more often decreased flexion <0 001
	<80°	4	4		13	7		5	2		22	13		
Medial or lateral instability	<10°	18	13	( )	12	5	(-)	29	6	(-)	59	24	(-)	0 069
	≥10°	43	25		50	29		71	24		164	78		
Quadriceps power	≥100N	17	7	(-)	9	4	(-)	32	8	0 05	58	19	0 028	Guépar worse quadriceps power 0 003
	≤100N	15	10		38	24		47	22		94	50		
Varus-valgus at weight-bearing	<10°	27	16	(-)	16	7	(-)	46	12	(-)	89	35	(-)	Guépar more often malposition < 0 0001
	≥10°	37	25		44	26		53	17		134	68		
Pain at rest	Yes	36	23	(-)	40	24	( )	59	16	(-)	135	63	(-)	(-)
	No	31	21		24	10		50	17		105	48		
Function preoperatively Need of support at walking indoors	Yes	37	29	0 012$^{x)}$	43	26	0 092	65	21	(-)	145	76	0 018	Guépar increased need of support <0 001
	No	30	15		21	8		44	12		95	35		
ARA functional classification	II IIIa	21	12	(-)	16	4	0 009	62	15	(-)	99	31	<0 001	Guépar worse functional classification <0 0001
	IIIb IV	43	29		48	30		47	18		138	77		

	McIntosh (67)			Guépar (64)			Marmor (109)			Total material (240)			Population difference
	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Chi^2 p
Hip arthroplasty ipsilateral													
Yes	8	7		7	4		11	5		26	16		
No	59	37	(-)	57	30	(-)	99	28	(-)	214	95	0 04	(-)
Hip arthroplasty contralateral													
Yes	10	9		8	6		14	5		32	20		
No	57	35	0 079	56	28	(-)	95	28	(-)	208	91	0 015	(-)
Status in the knee preoperatively													
Exudate Yes	39	27		28	12		71	21		138	60		
No	26	15	(-)	36	18	(-)	36	10	(-)	98	43	(-)	McIntosh more often exudate <0 0001
Capsular swelling													
Yes	60	38		36	21		77	23		173	82		
No	6	5	(-)	28	13	(-)	32	10	(-)	66	28	(-)	McIntosh more often capsular swelling <0 0001
FP joint crepitations													
Yes	45	29		47	29		80	23		172	81		
No	14	7	(-)	4	0	(-)	11	3	(-)	29	10	(-)	McIntosh less often crepitation 0 007
Fixation of patella													
Yes	43	28		23	15		53	16		119	59		
No	14	7	(-)	27	13	(-)	38	11	(-)	79	31	(-)	McIntosh more often fixation 0 042
Anterior drawer sign													
Yes	34	23		34	21		63	21		131	65		
No	22	10	0 099	22	11	(-)	25	5	0 079	69	26	<0 001	(-)

	McIntosh (67)			Guepar (64)			Marmor (109)			Total material (240)			Population difference
	Knees	Not satis-factory	p	Knees	Not satis factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Chi^2 p
Pain at walking at follow-up													
Knee contralateral													
Yes	34	23	(-)	23	18	0 003	45	16	(-)	102	57	0 01	(-)
No	33	21		41	16		64	17		138	54		
Hip ipsilateral													
Yes	8	8	0 027	9	5	(-)	10	4	(-)	27	17	0 047	0 068
No	58	35		55	29		99	29		212	93		
Hip contralateral													
Yes	11	11	0 008	8	6	(-)	10	4	(-)	29	21	0 009	(-)
No	55	32		56	28		99	29		210	89		
Foot - foot joint ipsilateral													
Yes	22	16	(-)	19	8	(-)	28	9	(-)	59	33	0 079	(-)
No	44	27		45	26		81	24		180	77		
Foot - foot joint contra-lateral													
Yes	21	15	(-)	17	8	(-)	30	11	(-)	68	34	(-)	(-)
No	45	28		47	26		79	19		171	73		
Pathology at operation													
Destruction of ligaments													
Yes	38	25	(-)	39	20	( )	74	19	0 065	151	64	0 04	0 06
No	27	18		25	14		32	14		84	46		
Attrition of bone													
Yes	31	18	( )	9	5	(-)	40	13	(-)	80	36	(-)	Guépar more often attrition
No	35	25		55	29		69	20		159	74		<0 001

	McIntosh (67)			Guépar (64)			Marmor (109)			Total material (240)			Population difference
	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Knees	Not satis-factory	p	Chi^2 p
Hip arthroplasty ipsilateral													
Yes	8	7	(-)	7	4	(-)	11	5	(-)	26	16	0 04	(-)
No	59	37		57	30		99	28		214	95		
Hip arthroplasty contralateral													
Yes	10	9	0 079	8	6	(-)	14	5	(-)	32	20	0 015	(-)
No	57	35		56	28		95	28		208	91		
Status in the knee preoperatively													
Exudate Yes	39	27	(-)	28	12	(-)	71	21	(-)	138	60	(-)	McIntosh more often exudate < 0 0001
No	26	15		36	18		36	10		98	43		
Capsular swelling													
Yes	60	38	(-)	36	21	(-)	77	23	(-)	173	82	(-)	McIntosh more often capsular swelling < 0 0001
No	6	5		28	13		32	10		66	28		
FP joint crepitations													
Yes	45	29	(-)	47	29	(-)	80	23	(-)	172	81	(-)	McIntosh less often crepitation 0 007
No	14	7		4	0		11	3		29	10		
Fixation of patella													
Yes	43	28	(-)	23	15	(-)	53	16	(-)	119	59	(-)	McIntosh more often fixation 0 042
No	14	7		27	13		38	11		79	31		
Anterior drawer sign													
Yes	34	23	0 099	34	21	(-)	63	21	0 079	131	65	< 0 001	(-)
No	22	10		22	11		25	5		69	26		

VII GENERAL DISCUSSION

RESULTS

By comparing the frequencies of pathological findings preoperatively and at follow-up in the three arthroplasty materials the extent to which the methods were effective can be assessed This is illustrated in the Venn diagrams on pages 25 55 and 70 as well as by the other criteria included in Weinfeld s evaluation system

Table 48
Calculated % from Venn diagrams pages 25 55 and 70

%	McIntosh (67)		Guépar (64)		Marmor (109)	
	Preop	Follow-up	Preop	Follow-up	Preop	Follow-up
I	97	60	88	25	93	17
II	75	51	84	10	79	53
III	25	6	44	3	30	5
I+II	72	37	73	2	73	17
I+III	24	6	36	0	28	0
II+III	19	3	30	2	22	2
I+II+III	18	3	27	0	21	0
Outside diagram	0	27	0	64	0	44

I Pain

Pain was a major indication in 88 % – 97 % of the knees The difference in the subsets was not significant At follow-up pain was found in 60 % in the McIntosh material, in 25 % in the Guépar material and in 17 % in the Marmor material

II Instability – varus/valgus malposition

Preoperative lateral instability and/or malposition exceeding 10° at weight-bearing was present in 75 % (McIntosh) to 84 % (Guépar) of knees the Guépar material had a higher frequency of extreme malposition and varus was more usual than valgus At follow-up correction of malposition and/or lateral instability was significantly better when using the Guépar only 10 % were not corrected as compared to 51 % and 53 % for the McIntosh and Marmor arthroplasties respectively Lateral instability and/or malposition after Guépar arthroplasty was caused of eccentric position of the prosthesis in the marrow

DISCUSSION

In clinical work, it is usually necessary to accept differences in compared populations Normally, the population characteristics are so complex that for practical use it seems more realistic to ignore the differences than to define them This causes much uncertainty in assessment and might lead to serious errors Tew and Waugh (1978), on the basis of five arthroplasty materials evaluated according to the criteria recommended by the British Orthopaedic Association Research Subcommittee showed that only average age at operation was equal in these series whereas the difference in all the other registered preoperative criteria was highly significant ($p < 0.001$) which implies that these materials were statistically different populations and therefore direct comparison between them is of doubtful relevance

The three subsets in this work were characterized by a high degree of equality in population, the difference were well defined and comparisons therefore are permitted with an acceptable level of certainty

VII GENERAL DISCUSSION

RESULTS

By comparing the frequencies of pathological findings preoperatively and at follow-up in the three arthroplasty materials, the extent to which the methods were effective can be assessed This is illustrated in the Venn diagrams on pages 25, 55 and 70 as well as by the other criteria included in Weinfeld s evaluation system

Table 48
Calculated % from Venn diagrams pages 25, 55 and 70

%	McIntosh (67)		Guépar (64)		Marmor (109)	
	Preop	Follow-up	Preop	Follow-up	Preop	Follow-up
I	97	60	88	25	93	17
II	75	51	84	10	79	53
III	25	6	44	3	30	5
I+II	72	37	73	2	73	17
I+III	24	6	36	0	28	0
II+III	19	3	30	2	22	2
I+II+III	18	3	27	0	21	0
Outside diagram	0	27	0	64	0	44

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Pain was a major indication in 88 % - 97 % of the knees The difference in the subsets was not significant At follow-up pain was found in 60 % in the McIntosh material in 25 % in the Guépar material and in 17 % in the Marmor material

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cavities or loosening secondary to deep infection After hemiarthroplasty the following reasons for instability and/or malposition were found 19 knees had severe attrition of one or both femoral condyles which developed after insertion of the prosthesis (Fig 6a and b) A significantly worse result was found when attrition had developed in the femoral condyles In 30 knees malposition of one or both prostheses was found, in 20 of them this increased or developed entirely during the observation period In unconstrained total arthroplasty (Marmor), resurfacing was done on both the femur and the tibia and postoperative attrition therefore prevented Loosening of one or both tibial components in 44 knees and altered position of one or both tibial components was found in 40 of 86 knees The common use of a 6 mm tibial component was considered an important reason for the high rate of loosening and alteration of position Ligamentary insufficiency was also important with regard to instability following Marmor arthroplasty Where congruency was obviously not achieved at surgery, subluxation and collapse of medial compartment occurred

III Extension defect

The preoperative frequency of extension defect in the Guépar material (44 %) was significant greater, than in the McIntosh and Marmor materials In constrained arthroplasty, an extension defect could be eliminated regardless of the amount A risk with extreme resection of bone was the development of an extension lag, in two knees (3 %), an extension lag exceeding 20° was found at follow-up Compared with the unconstrained principle, the result was very satisfactory In unconstrained arthroplasty, an extension defect can be corrected by resection of the anterior edge of the tibial plateau The tibial component must often of necessity be placed in an anterior inclination if full extension is to be achieved Even though significantly worse results at follow-up after McIntosh and Marmor arthroplasty were not shown when extension defects were present at surgery, it must be considered a disadvantage that the normal dorsal translocation of the femur in relation to the tibia on flexion was probably diminished as a result of anterior inclination After McIntosh arthroplasty, an extension defect exceeding 15° was found at follow-up in four knees (6 %), in Marmor arthroplasty in four knees (5 %) Independent of arthroplasty principle a significant decrease of operative extension defect was achieved

Flexion Limited flexion was not of major importance as an indication in any of the knees When extension defects were eliminated at operation it was not always possible to increase the range of motion by the amount that the extension defect was diminished, probably because of a decreased amplitude in the extensor apparatus Consequently because of a higher incidence of considerable extension defects preoperatively in the

Guépar material a higher frequency of knees with less than 80° flexion was found after constrained arthroplasty

Quadriceps power Preoperative weak quadriceps was significantly more often present in the Guépar material than in the other two subsets also at follow-up weak quadriceps was more often present following constrained than unconstrained arthroplasty This might to some extent be caused by the extension lag after correction of large extension defects in the Guépar material This can also po sibly be accounted for by the inbuilt hyperextension in the Guépar prosthesis which permits walking without contraction of the quadriceps From the preliminary examination to follow-up there was a decrease in quadriceps power in the Guépar material probably secondary to loosening of the prosthesis After unconstrained hemi- and total arthroplasty there was equal frequencies of weak quadriceps Increased frequency of pain at weight-bearing in the McIntosh material at follow-up led one to expect a higher frequency of weak quadriceps in this material but it was probably compensated for by the lower average age in this subset

Conclusion of result at follow-up

Following arthroplasty the minimum expectation was that the knees postoperatively and at least for some years should be almost painfree stable and free of deformity and this was so after Guépar arthroplasty in 64 % of the knees after Marmor arthroplasty in 44 % and after McIntosh arthroplasty in 27 % The constrained principle produced according to these criteria a better result than did unconstrained arthroplasty although 25 % of the knees at follow-up were still considerable painful

A comparison of hemi- with unconstrained total arthroplasty showed that they were equally able to correct lateral instability malposition and extension defect After hemiarthroplasty there was an unacceptable frequency of pain at follow-up in 60 % compared to only 17 % after unconstrained total arthroplasty The McIntosh hemiarthroplasty was not superior to the Marmor arthroplasty in any aspect discussed here and can no longer be regarded as a rational alternative in surgery of the knee in RA

cavities or loosening secondary to deep infection After hemiarthroplasty the following reasons for instability and/or malposition were found 19 knees had severe attrition of one or both femoral condyles which developed after insertion of the prosthesis (Fig 6a and b) A significantly worse result was found when attrition had developed in the femoral condyles In 30 knees malposition of one or both prostheses was found, in 20 of them this increased or developed entirely during the observation period In unconstrained total arthroplasty (Marmor), resurfacing was done on both the femur and the tibia and postoperative attrition therefore prevented Loosening of one or both tibial components in 44 knees and altered position of one or both tibial components was found in 40 of 86 knees The common use of a 6 mm tibial component was considered an important reason for the high rate of loosening and alteration of position Ligamentary insufficiency was also important with regard to instability following Marmor arthroplasty Where congruency was obviously not achieved at surgery, subluxation and collapse of medial compartment occurred

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Table 50
Technical difficulties – operative complications

	McIntosh (67)	Guépar (64)	Marmor (109)
Operative fractures	8	6	9
Subchondral cysts	7	4	7
Wrong prosthesis	5	1	–
FP joint problems	1	17	15
Extension defect	2	4	4
Incongruency	2	–	7
Cementation problems	–	–	7
Miscallaneous	–	–	9
TOTAL	25 (37 %)	32 (50 %)	58 (53 %)

Operative fractures The most usual type of fracture in McIntosh and Marmor arthroplasty was detachment of the eminentia resulting in loosening of the insertion of the anterior cruciate ligament which resulted in sagittal instability
In Guépar arthroplasty 5 of 6 fractures were perforations of the femoral and the tibial diaphyses which occurred during reaming or at insertion of the prosthesis although continuity of the bone was present the results were uniformly not satisfactory

FP joint problems In McIntosh arthroplasty the FP-joint was not influenced by the operation In only one knee with lateral subluxation of the patella preoperatively was the patella found dislocated postoperatively
In Guépar arthroplasty a hemiarthroplasty is automatically performed in the FP-joint, but the trochlea of the prosthesis is not anatomical in design During the operation 17 knees had dislocation of the patella Although precautions were taken dislocation was found in two knees postoperatively The reason for the high frequency of dislocated patella in Guépar arthroplasty was probably multifactorial but the forced outward rotation of the tibia by traction on the patella ligament during lateral dislocation of the patella during cementing was considered important In operative patellar dislocations the risk of complicated wound healing increases No increased risk of late infection was shown
In 15 knees where Marmor arthroplasty was done the anterior edge of one or both prostheses was prominent in facies patellaris and at flexion impinged on the patella Patellectomy was indicated in 12 knees because of impingement

Incongruency In unconstrained arthroplasty incongruency at surgery indicated a poor prognosis because the fundamental need for soft tissue stability was not achieved

Table 49
Result according to Weinfeld

Points	McIntosh (67)		Guépar (64)		Marmor (109)	
	Preop	Follow-up	Preop	Follow-up	Preop	Follow-up
Pain (0-7)	6 1	3 3	5 9	1 3	5 9	1 4
Use of support at walking (0-4)	1 9	2 1	3 1	2 3	2 5	1 2
Extension defect (0-4)	1 0	0 3	1 4	0 2	1 1	0 3
Flexion (0-6)	0 0	0 3	0 3	0 4	0 1	0 1
Medial or lateral instability (0-4)	1 4	0 8	2 0	0 1	1 5	0 9
Varus-valgus at weightbearing (0-4)	1 2	0 7	1 7	0 1	1 1	0 4
Quadriceps power (0-4)	2 9	1 3	3 5	2 3	3 2	1 4
Sum demerit points	14 5	8 8	17 9	6 7	15 3	5 7

Preoperatively, there was a significantly higher score in the Guépar material and the average improvement in points was higher than in the other subsets, as a percentage of the preoperative score, the improvement was equal in the Guépar and the Marmor materials Preoperatively, the McIntosh material had the lowest point score and at follow-up the highest point score, which implies the worst result At follow-up, the lowest average point score was found in the Marmor material

COMPLICATIONS

Technical difficulties and operative complications reflect the difficulties with a chosen technique and the pathological changes present in the knee in reconstructing a stable, mobile articulation In the Guépar material, increased deformity was found preoperatively, but despite that, there was a lower frequency of complications than in the Marmor material

Table 50

Technical difficulties – operative complications

	McIntosh (67)	Guépar (64)	Marmor (109)
Operative fractures	8	6	9
Subchondral cysts	7	4	7
Wrong prosthesis	5	1	-
FP joint problems	1	17	15
Extension defect	2	4	4
Incongruency	2	-	7
Cementation problems	-	-	7
Miscellaneous	-	-	9
TOTAL	25 (37 %)	32 (50 %)	58 (53 %)

Operative fractures The most usual type of fracture in McIntosh and Marmor arthroplasty was d tachment of the eminentia resulting in loosening of the insertion of the anterior cruciate ligament which resulted in sagittal instability
In Guépar arthroplasty 5 of 6 fractures were perforations of the femoral and the tibial diaphyses which occurred during reaming or at insertion of the prosthesis although continuity of the bone was present the results were uniformly not satisfactory

FP-joint problems In McIntosh arthroplasty the FP-joint was not influenced by the operation In only one knee with lateral subluxation of the patella preoperatively was the patella found dislocated postoperatively
In Guépar arthroplasty a hemiarthroplasty is automatically performed in the FP-joint but the trochlea of the prosthesis is not anatomical in design During the operation, 17 knees had dislocation of the patella Although precautions were taken dislocation was found in two knees postoperatively The reason for the high frequency of dislocated patella in Guépar arthroplasty was probably multifactorial but the forced outward rotation of the tibia by traction on the patella ligament during lateral dislocation of the patella during cementing was considered important In operative patellar dislocations the risk of complicated wound healing increases No increased risk of late infection was shown
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Technical difficulties and operative complications reflect the difficulties with a chosen technique and the pathological changes present in the knee in reconstructing a stable, mobile articulation In the Guépar material, increased deformity was found preoperatively, but despite that, there was a lower frequency of complications than in the Marmor material

impingment of the patella on the anterior edge of the femoral component, in four, the pain later diminished without treatment

Table 52
Late postoperative complications

	McIntosh (67)	Guépar (64)	Marmor (109)
Late infection	-	15	2
Dislocation of the patella	1	5	-
Dislocation of prosthesis	2	-	7
Collapse of condyles	3	-	3
Fracture	2	1	2
Miscellaneous	-		2
TOTAL	8 (12 %)	21 (33 %)	16 (14 6 %)

Late infection After McIntosh arthroplasty no incidence of late infection was noted, although no prophylactic antibiotics were used In Guépar arthroplasty late infection developed in 15 knees in only four was there delayed wound healing Increased frequency of deep infection was found after transfer of the tibial tuberosity and when no prophylactic antibiotics were used The consequence of deep infection was considerable two patients died of septicaemia one above-knee amputation was carried out on vital indication and five were reoperated with change of prosthesis or arthrodesis After Marmor arthroplasty deep infection developed in two knees one patient died of septicaemia caused by haematogenous spread from an infected varicose ulcer

Dislocation of the patella After McIntosh arthroplasty lateral dislocation of the patella was found in one knee This was probably secondary to subluxation of the tibia After Guépar arthroplasty the patella dislocated laterally in five knees Reoperation with capsular plication or transfer of the tibial tuberosity was performed in three In the Marmor material no additional FP-joint problems developed after two months had elapsed since surgery

Loosening of prosthesis - dislocation After McIntosh arthroplasty dislocation of the prosthesis was found in two knees with severe clinical symptoms After Marmor arthroplasty, total collapse with a compression fracture and loosening of the prosthesis in the medial compartment developed in six knees where congruency between the tibial and the femoral components was not achieved at surgery Because of the short observation period in the Marmor material and a known high frequency of loosening of components an increase of this complication can be predicted

Cementation problems In Marmor arthroplasty in seven knees, stable fixation of one or both tibial components was not achieved at the first cementing attempt Lack of jigs and instruments for fixing the prosthesis in the desired position during cementing was considered the main reason for these failures

Table 51

Postoperative complications (complications noted less than two months after operation)

	McIntosh (67)	Guépar (64)	Marmor (109)
General			
Cardiopulmonary	-	3	4
Others	-	1	2
Local			
Complicated wound healing	4	13	11
Deep infection	-	1	-
FP-joint problems	1	2	5
Dislocation of prosthesis	1	-	2
Peroneal palsy		3	7
Fractures	-	1	1
Others	2	1	9
Total local complications	8 (12 %)	21 (33 %)	35 (32 %)

Complicated wound healing

After Guépar arthroplasty, complicated wound healing was found in 13 knees (20 %) The frequency was thus twice as high as in Marmor arthroplasty, although the extremity was immobilized in plaster for two weeks for optimum wound healing Detachment of the tuberosity and dislocation of the patella at surgery and postoperatively predisposed to delayed wound healing Prophylactic antibiotics had no influence on the frequency of complicated wound healing In four knees with wound healing problems, a late infection developed afterwards (resulting in one death, one above-knee amputation, and one change of prosthesis) The time spent in hospital was increased on average 44 % when complicated wound healing was present In the Marmor material an increased frequency of complicated wound healing after patellectomy and previous knee operations was found

FP-joint problems In two knees the patella dislocated laterally after Guépar arthroplasty, although a capsular plication was carried out at surgery After Marmor arthroplasty in five knees, crepitations and femoro-patellar pain on flexion were caused by

impingement of the patella on the anterior edge of the femoral component in four, the pain later diminished without treatment

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Late postoperative complications

	McIntosh (67)	Guépar (64)	Marmor (109)
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Miscellaneous	-		2
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Collapse of condyles After McIntosh arthroplasty, a progressing collapse developed in the lateral femoral condyle in two knees and in one with a primary demiarthroplasty, an increasing destruction of the other compartment was noted After Marmor demiarthroplasty there was a collapse in the non-operated compartment in 3 of 9 knees and reoperation with insertion of a prosthesis in this compartment was carried out In another two considerable pain was experienced at weight-bearing Unicompartment operation did *not seem to be justified in RA even if one compartment at surgery was found well preserved*

VIII SUMMARY

Functional results

On Weinfeld s evaluation there was a significantly higher preoperative score and at follow up the highest improvement in points in constrained arthroplasty (Guépar) but the percentage of improvement was equal in both the constrained and unconstrained (Marmor) total arthroplasty The lowest point score at follow-up, which implies the best result according to Weinfeld s evaluation system, was found in the Marmor material The lowest preoperative and the highest follow-up score was found in the McIntosh material which implies that the result in hemiarthroplasty is inferior to total arthroplasty Following arthroplasty the minimum expectation was that the knees postoperatively and at least for some years thereafter should be relatively painless stabile and free of deformity These demands were fulfilled after constrained arthroplasty in 64 % of the knees, after unconstrained total arthroplasty in 44 % and after hemiarthroplasty in 27 % of the knees The constrained principle which secures correct alignment of femur and tibia and lateral stability and elimination of extension defect gave better results than the unconstrained arthroplasty although 25 % of the knees at follow-up still had considerable pain

Technical difficulties and operative complications

The lowest incidence of technical difficulties or operative complications was seen in hemiarthroplasty (McIntosh) in 25 knees (37 %) The dominant problems were detachment of the anterior cruciate ligament presence of subchondral cysts and attrition of condyles, which made the prosthetic principle insufficient for reconstruction

The most severe pathological changes were found in the Guépar material In 32 (50 %) of the constrained arthroplasties technical difficulties or complications were noted Not satisfactory results were found after perforation of the diaphysis although continuity of the bone was present allowing full weight-bearing After correction of extreme extension defects remaining extension lag was found in two knees Considerable FP-joint problems were noted operative dislocation of the patella was common and regarded as generally caused by forced outward rotation of the tibia and the shape of the patella facet on the prosthesis

The highest incidence of technical difficulties and operative complications were found in unconstrained total arthroplasty (Marmor) in 58 knees (53 %) Damage to the insertion of the anterior cruciate ligament difficulties in cementation of the tibial components, Incongruency between femoral and tibial components and passive extension defects were

Collapse of condyles After McIntosh arthroplasty, a progressing collapse developed in the lateral femoral condyle in two knees and in one with a primary demiarthroplasty, an increasing destruction of the other compartment was noted After Marmor demiarthroplasty there was a collapse in the non-operated compartment in 3 of 9 knees and reoperation with insertion of a prosthesis in this compartment was carried out In another two considerable pain was experienced at weight-bearing Unicompartment operation did not seem to be justified in RA even if one compartment at surgery was found well preserved

IX REFERENCES

Ahlbäck, S (1968) Osteoarthrosis of the knee A radiographic investigation Acta Radiol Suppl 277

Alnot, J Y Aubriot, J H , Deburge A Dyboosset J F , Kenesi, C Mazas, F , Patel A and Schramm P (G U E P A R -group, Paris) (1971) Total arthroplasia of the knee Review of orthopaedic and repair surgery of the motor system (Paris) 57, no 7, 575

Andersen, J L , Egund, N and Laurusdottir H The radiological findings in unconstrained knee arthroplasty To be published

Andersson G (1972) Hip assessment A comparison of nine different methods J Bone Joint Surg 54-B, 4, 621

Andersson G Jessop J Freeman M A R and Mason R M (1973) McIntosh arthroplasty in rheumatoid arthritis Exerpta Med The International Congress on the knee joint Rotterdam 1

Arden G P (1973) Complications of total knee replacement and their treatment The Knee Joint Recent advances in basic research and clinical aspects Proceedings of the International Congress in Rotterdam September 13-15 pp 221-227

Arden G P (1973) Total knee replacement Clin Orthop 94, 103

Bain A M (1973) Replacement of the knee joint with the Walldius prosthesis using cement fixation Clin Orthop 94 65

Baldursson H Hansson L I Olsson T H and Selvik G Migration of acetabular socket after total hip replacement determined with roentgen stereophotogrammetry Accepted for publication in Acta Orthop Scand

Berglund K Brattström M Claesson K and Kristiansson G (1973) Erfarenheter från ambulant rehabilitering av patienter med kronisk artrit Läkartidn 70 8, 721

Blum B Mowat A G Bentley G and Norris J R (1974) Knee arthroplasty in patients with rheumatoid arthritis Ann Rheum Dis 33 1

Blundell Jones G (1973) Total knee replacement – the Walldius hinge Clin Orthop 94 50

Brattström H and Brattström M (1971) Long-term results in knee arthrodesis in rheumatoid arthritis Reconstructive surgery and traumatology 12 125

Brattström H (1973) Personal communication

Burrough S J Clark M J Taylor A R and Hill A G S (1973) An on-going prospective study of the McIntosh arthroplasty Exerpta Med The International Congress on the knee joint Rotterdam 32

Cavendish M E and Wright J T (1978) The Liverpool McJoe Knee prosthesis J Bone Joint Surg 60-B 3 315

caused by a too optimistic use of the method in knees where the pathological changes were too advanced and partly caused by the lack of jigs for resection and for retaining the tibial components during cementation In the FP-joint, the prosthesis had a harmful effect Prominence of the anterior edge of the femoral component caused patella impingement, patellectomy was therefore indicated in 12 knees

Postoperative complications

The lowest incidence of complications was found after hemiarthroplasty (McIntosh) The wound in only four knees failed to heal within four weeks

After constrained arthroplasty (Guépar), there were no general complications of a serious nature In two knees, the patella dislocated postoperatively, although operative capsular plication was done The biggest problem was complicated wound healing in 20 % of the knees Patellar dislocation and transfer of the tibial tuberosity operatively predisposed to delayed wound healing Complicated wound healing resulted in an increase of hospital stay and late infection developed in four of the knees

After unconstrained total arthroplasty (Marmor), there was the same incidence of complications as after Guépar arthroplasty (32 %) Impingement of the patella on the femoral prosthesis caused by its design and position, was noted in five knees In two knees, prosthetic components were loose in the postoperative period In 10 % of the knees, the wound failed to heal within four weeks, patellectomy predisposed to complicated wound healing

Late complications

Following hemiarthroplasty (McIntosh), the important complications were dislocation of the prosthesis and collapse of the non-resurfaced condyles

After constrained arthroplasty (Guépar), the dominating problems were late infections in 15 knees (23 %) with serious consequences such as death, amputation and change of prosthesis Dislocation of the patella occurred during the observation period in five knees

After unconstrained total arthroplasty (Marmor), loosening of the prosthetic components was found in seven knees and in three knees, primary demiarthroplasties were reoperated with a prosthesis in the other compartment because of collapse of this non-operated compartment

Lettin A W F Deliss L J Blackburn, J S and Scales, J T (1978) The Stanmore hinge knee arthroplasty J Bone Joint Surg 60-B 3 327

Lindberg L (1978) Diagnostik och behandling av djup infektion vid total höftleds-plastik Läkartidn 75, 1701

Marmor, L (1973) The modular knee Clin Orthop 94 242

Marmor, L (1976a) The modular (Marmor) knee Clin Orthop 120 86

Marmor L (1976b) Personal communication

Mazas F B (1973) Guépar total knee prosthesis Clin Orthop 94, 211

McIntosh, D L (1967) Arthroplasty of the knee in rheumatoid arthritis Second International Symposium of Synovectomy and arthroplasty in rheumatoid arthritis Basel Switzerland

McIntosh D L and Hunter G A (1972) The use of the hemi arthroplasty prosthesis for advanced osteoarthritis and rheumatoid arthritis of the knee J Bone Joint Surg 54-B 244

Murray W R (1967) Arthroplasty of the knee in rheumatoid arthritis J Bone Joint Surg 49-A 193

Nelson C L and Evarts C M (1971) Arthroplasty and arthrodesis of the knee joint Orthop Clin North Am 2 245

Neville R M K and Martins H D (1972) The McIntosh tibial plateau hemiprosthesis for the rheumatoid knee J Bone Joint Surg 54-B 256

Olerud S Modig J and Busch C (1973) Utsvämning av intramedullära produkter till lungcirkulationen och deras möjliga inverkan på lungfunktionen vid total höftledsplastik Sammanfattning Medicinska Riks stämman Stockholm

Potter T A (1969) Arthroplasty of the knee with tibial metallic implants of the McKeever and McIntosh design Surg Clin North Am 49 903

Schorn G Bentley G Deane G and Mowat A G (1970) Knee arthroplasty in rheumatoid arthritis Rheumatology and Rehabilitation

Shaw N E and Chatterjee R K (1978) Manchester knee arthroplasty J Bone Joint Surg 60 B 3 310

Shiers L P G (1954) Arthroplasty of the knee Preliminary report of a new method J Bone Joint Surg 36-B 553

Shiers L P G (1960) Arthroplasty of the knee Interim report of a new method J Bone Joint Surg 42-B 31

Sjöstrand L -O (1974) Radionuclide scintimetry of total hip arthroplasty Thesis Lund University

Sneppen O Fredensborg N Karle A and Klaumann O (1978) Lateral dislocation of the patella following Marmor and Guépar arthroplasty of the knee Acta Orthop Scand 49- 291

Conaty, J P (1973) Surgery of the hip and knee in patients with rheumatoid arthritis J Bone Joint Surg 55-A, 2, 301

Deburge, A (1976) Guépar hinge prosthesis Clin Orthop 120, 47

Engelbrecht, E , Sigel, A , Röttger, J and Buchholz, H W (1976) Statistics of total knee replacement, partial and total knee replacement design St Georg Clin Orthop 120, 54

Freeman, P A (1973) Walldius arthroplasty A review of 80 cases Clin Orthop 94, 85

Golding, D N (1966) A synopsis of rheumatic diseases John Wright and Sons Ltd , Bristol, 41

Goddfellow, J and O Connor, J (1978) The mechanics of the knee and prosthesis design J Bone Joint Surg 60-B, 3, 359

Grobbelaar, C J , Do Plessis, T A , Murray, F (1978) The radiation improvement of polyethylene prosthesis J Bone Joint Surg 60-B, 3, 370

Hagstedt, B (1974) High tibial osteotomy for gonarthrosis Thesis, Department of Orthopaedic Surgery, Lund

Hallén, L G , and Lindahl, O (1965) The lateral stability of the knee-joint Acta Orthop Scand 36, 179

Hastings, D E and Hewitson, W A (1973) Double hemiarthroplasty of the knee in rheumatoid arthritis J Bone Joint Surg 55-B, 1, 112

van Hussen, F A J (1973) *Movement of the knee during locomotion in patients with* a Walldius prosthesis Proceedings of the International Congress in Rotterdam p 54

Insall, J N , Ranawat, C S , Aglietti, P and Shine, J (1976) A comparison of four models of total knee replacement prosthesis J Bone Joint Surg 58-A, no 6, 754

Jani, L and Morscher, F (1973) Erfahrungen mit der Kniearthroplastik nach McIntosh Arch *Orthopädie und Unfallchir* 75, 81

Jessop, J D and Moore, C J (1972) Follow-up of the McIntosh arthroplasty of the knee joint Rheumatology and Physical Medicine II, 217

McKeever, D C)1959) Tibial plateau prosthesis Clin Orthop 18, 86

Kellgren, J H , and Samuel E P (1950) The sensitivity and innervation of the articular capsule J Bone Joint Surg 32-B, 1, 84

Kenwright and Duthie (1971) Arthritis of the knee, replacement arthroplasty Seminars in arthritis and rheumatism I, I

Kenesi, C (1978) Early general complications in total knee prostheses with cemented hinges Year Book of Orthopaedics and Traumatic Surgery

Klaumann, O , Christiansen, H , Karle, A and Sneppen, O (1978) Knä-alloplastik Ugeskr Laeg 140, 37, 2243

Laskin, R S (1976) Modular total knee replacement arthroplasty J Bone Joint Surg 58-A, 6, 766

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Tew, M and Waugh, W (1979) Total replacement of the knee J Bone Joint Surg 61-B, 2, 225

Turner, R A , Brown, E M , Sbarbaro, J L and Hollander, J L (1972) Arthroplasty of the knee with tibial and of femoral metallic implants in rheumatoid arthritis Arthritis Rheum 15, 1

Wahlig, H , Dingeldein, E , Bergmann, R , Reuss, K (1978) The release of gentamicin from polymethylmethacrylate beads J Bone Joint Surg 60-B, 270

Walldius, B (1957) Arthroplasty of the knee using an endoprosthesis Acta Orthop Scand Suppl 24

Walldius, B (1960) Arthroplasty of the knee using an endoprosthesis Eight years experience Acta Orthop Scand 30, 137

Watson, J R , Wood, H and Hill, R C J (1976) Shiers arthroplasty of the knee J Bone Joint Surg 58-B, 300

Wilson, F C and Venters, C (1976) Results of knee replacement with the Walldius prosthesis Clin Orthop no 120, 39

Wivoet, J and the Guépar-group (1973) Guépar total knee prosthesis Excerpta Medica, Rotterdam

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BERNARDI SIEGFRIED ALBINI

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Qua denique eadem illa cauda pone caput superius tibiae incedit ibi inter eam & capsam genu bursa parva

De gemello —

Capiti ejus interiori subjacet bursa magna accreta firmiter tendineae parti illius capitis extremoque Semitendinosi & capsae genu juxta condylum interiorem

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To Helga and Carl Carlson

CONTENTS

To Helga and Carl Carlson

DEFINITION

The author defines a popliteal cyst as a communicating gastrocnemio semimembranosus bursa which is constantly or temporarily distended by synovial fluid and *not* as a cyst originating from the tendon sheath of the popliteus muscle

ABBREVIATIONS

g s bursa	= gastrocnemio semimembranosus bursa
I A N C	= International Anatomical Nomenclature Committee third edition 1966
B N A	= Basle Nomina Anatomica 1895
J N A	= Jena Nomina Anatomica 1935
P N A	= Paris Nomina Anatomica i e the first edition of the Nomina Anatomica I A N C 1955

KEY WORDS

Popliteal cyst
Baker s cyst
popliteal bursa
surgical anatomy
functional anatomy

INTRODUCTION

EARLY CLINICAL OBSERVATIONS CONCERNING POPLITEAL CYSTS

The first mention of a cystic swelling in the popliteal region was made by *Dupuytren* who in 1829 reported on a patient with an enormous hydrops in the knee joint In 1840 *Adams* described in detail a chronic inflammatory knee disease which he was the first to designate chronic rheumatoid arthritis He believed that the first link in the morbid chain was the disease of the synovial membrane contradicting Cruveilhier among others who considered that the disease started in the cartilage (usure des cartilages) He also stated that the affection was very chronic and impossible to cure although it was sometimes benefited by rest In a comprehensive review concerning abnormal conditions of the knee joint (1839—1847) Adams reported that in the majority of such cases he had palpated a cystic tumour in the medial part of the popliteal region in fact so often that he considered this to be a reliable symptom of the rheumatic joint affection On inspection it took the shape of a very well defined ovoid projection adjacent to the inner hamstring muscles which was felt to be very tense in the extended position He stated *If we feel this bursa and then cause* the patient s limb to be flexed we can follow the fluid with our fingers into the articulation Through his own dissections he established that this cyst mainly consisted of an enlargement and dropsical condition' of the bursa which naturally exists at the decussation of the semimembranosus tendon with the tendon of the internal head of the gastrocnemius Adams found that in some cases this enlarged bursa communicated with the joint by a species of valvular opening In other cases small round apertures into the joint were observed

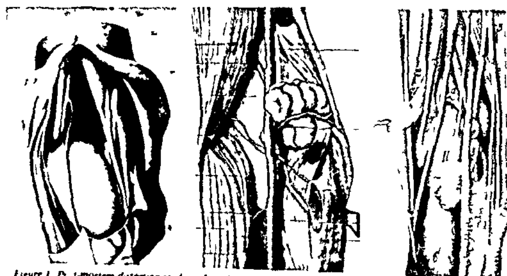


Figure 1 Post-mortem dissection studies of popliteal cysts performed by W Gruber
Left *Specimen from a young man who died of septicaemia following puncture of a popliteal cyst (1846)*
Middle *Hernial outpouching in an autopsy preparation (1865)*
Right *Large bursal hygroma detected by chance at post mortem examination (1835)*

INTRODUCTION

EARLY CLINICAL OBSERVATIONS CONCERNING POPLITEAL CYSTS

The first mention of a cystic swelling in the popliteal region was made by *Dupuytren* who in 1829 reported on a patient with an enormous hydrops in the knee joint In 1840 *Adams* described in detail a chronic inflammatory knee disease which he was the first to designate chronic rheumatoid arthritis He believed that the first link in the morbid chain was the disease of the synovial membrane contradicting Cruveilhier among others who considered that the disease started in the cartilage (usure des cartilages) He also stated that the affection was very chronic and impossible to cure although it was sometimes benefited by rest In a comprehensive review concerning abnormal conditions of the knee joint (1839—1847) Adams reported that in the majority of such cases he had palpated *a cystic tumour in the medial part of the popliteal region* in fact so often that he considered this to be a reliable symptom of the rheumatic joint affection On inspection it took the shape of a very well defined ovoid projection adjacent to the inner hamstring muscles which was felt to be very tense in the extended position He stated *If we feel this bursa and then cause the patient s limb to be flexed we can follow the fluid with our fingers into the articulation* Through his own dissections he established that this cyst mainly consisted of an enlargement and dropsical condition of the bursa which naturally exists at the decussation of the semimembranosus tendon with the tendon of the internal head of the gastrocnemius Adams found *that in some cases this enlarged bursa communicated with the joint by a species of valvular opening In other cases small round apertures into the joint were observed*

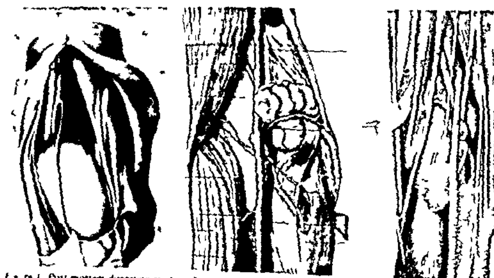
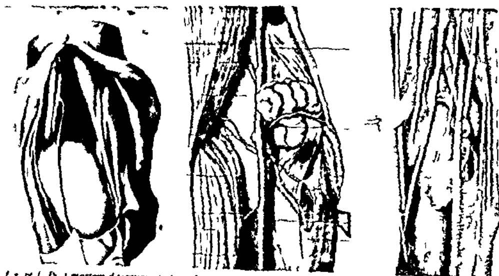


Figure 1 Post mortem dissection studies of popliteal cysts performed by W Gruber
Left *Specimen from a young man who died of septicaemia following puncture of a popliteal cyst (1846)*
Middle *Hernial ou pouching in an autopsy preparation (1865)*
Right *Large bursal hygroma detected by chance at post-mortem examination (1855)*

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Figure 2 Intermuscular synovial cysts in knee joints amputated because of tuberculous arthritis and dissected by Powers (1885 1887)

purulent inflammation such as subcutaneous discission opening and stuffing or packing or the insertion of setons Numerous fatal complications were reported as a result of such treatment (Gruber 1846 Heineke 1868 Baker 1877 Gribbon 1885) Surgical removal seems to have been performed for the first time by Malgaigne in the early 1850 s—one of his two patients died of septicaemia Only few excisions are reported from the antiseptic era as disastrous complications were common Since the introduction of asepsis several reports of uncomplicated surgical interventions in popliteal cysts have been made (Bond 1890 Hutton 1895 Sheild 1898 Hawkes 1899)

In a large number of knee dissection studies *Gruber* examined the posterior synovial recesses protrusions and communicating bursae (1845, 1846, 1857 1865, 1869, 1885) He formulated the concept of synovial herniation which was subsequently adopted by many authors Gruber published several papers concerning hygromas of enormous size" which he had observed by chance at routine post mortem examinations (Figure 1) Regarding the clinical implications he concluded that in below knee amputations the risk of an ascending knee joint arthritis via a communicating hernia had to be taken into account and suggested aspiration of the knee effusion through the bursa to minimise this hazard This was done by Pitha (1846) in a young man, but a fulminant arthritis rapidly developed and the patient died of septicaemia Gruber also dissected several amputation specimens and reported a popliteal fistula arising from a bursal perforation in a case of gonococcal arthritis and a large fistular system extending down to the tendon of Achilles in another case

In contrast to Gruber *Foucher* (1856) found in post mortem studies that all cysts arose from a bursa and none from synovial herniation (et ne comme un diverticulum, un hernie de la synoviale articulaire ') Foucher also referred to clinical reports on his own patients and those of contemporary physicians and noted that popliteal cysts could be emptied into the joint cavity by manual compression if the joint was in the flexed position whereas this was never possible with the knee extended This phenomenon has since been confirmed by other authors and has been referred to as the ' sign of Foucher (Heineke 1868 Goldscheider 1898)

Several doctoral theses have been devoted to the clinical aspects pathogenesis and therapy of popliteal cysts especially in the early French literature (Nelaton 1851, Longy 1852 Burguet 1854 Ollivier 1855 Baudouin 1855 Garnier 1890, Hemet 1900 Ciolina 1904)

In his two classic papers of 1877 and 1885 *Baker* reviewed two patients of his own and eight patients treated by contemporary physicians who had cystic tumours in the popliteal region He drew attention to the formation of synovial cysts in the leg in connection with disease of the knee joint and to the fact that most often the knee disease had begun some time before the appearance of the (secondary) cyst Commonly the joints were affected by what Baker called osteoarthritis He was not particularly specific about the pathogenesis of the cysts He considered that their formation was due to the fact that synovial fluid makes its way out of the knee and for most cases he held the hernial concept of Gruber, Billroth and others whereas for some he conceded that rupture of a communicating bursa or of a synovial hernia had allowed the cyst to form Five of Baker's patients eventually underwent amputation through the thigh

Power (1885, 1887) on examination of these amputation specimens, found severe destruction due to articular tuberculosis He exhibited some specimens at the Pathological Society of London and outlined the extension of the cysts and their communication with the joint cavity (Figure 2) In our day Maudsley and Arden (1961) have reviewed the clinical findings in Baker s patients and come to the conclusion that most of them suffered from tuberculosis of the joint and two from rheumatoid arthritis A histopathological re examination of Baker s knee specimens which have been preserved at St Bartholomew s Hospital Museum was undertaken by Gask and Wilson who found that they displayed signs of typical synovial tuberculosis

During the days of laudable pus ' conservative treatment with counter irritation compression and vesication with collodion and pressure and the application of a plaster of Paris bandage was common practice (Kirmisson 1892) More invasive methods of treatment did occur however such as puncture and tapping the injection of Morton s fluid caustics or iodine and still more aggressive procedures with the aim of producing

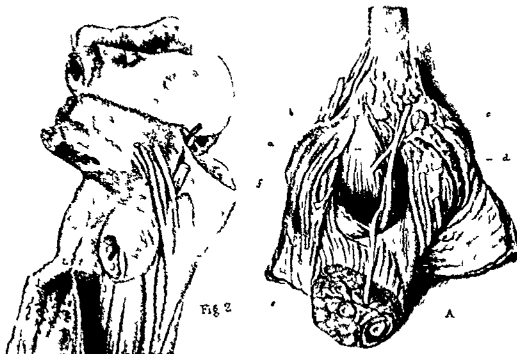


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Figure 3 Illustrations from Gruber s classical monograph Die Knieschleimbeutel (bursae mucosae synoviales) from 1857 showing synovial outpouchings through the tendon of the gastrocnemius muscle

the knee there was only a narrow slit Several authors including Brösicke (1899) Bardeleben Haeckel (1901) Fick (1904) Merkel (1907) Sonntag (1916—17) and Lewin (1952) have since agreed with this view

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THE ANATOMY OF THE POSTERO MEDIAL KNEE BURSAE

Albinus (1734) was the first anatomist to make mention of bursae at the postero medial aspect of the knee joint (see also frontispiece) The one situated between the semi *membranosus tendon and the capsule he de* nominated bursa parva and that beneath the medial head of the gastrocnemius muscle he called the bursa magna ' The latter bursa he found to be firmly adherent to the tendinous part of the gastrocnemius and semi tendinosus muscles and the capsule overlying the medial femoral condyle

Monro (1788) (Alexander Monro secundus) published a beautifully illustrated monograph of all the bursae mucosae of the human body One postero medial bursa he called the bursa vesicularis postica ad latus genus'' This opus was considerably enlarged by *Rosenmuller* for the German edition of 1799

The pathologist *Gruber* performed several series of meticulous dissection studies on at least *700 knees (1845, 1846 1856 1857,* 1865, 1869 1885) He gave a correct description of the gastrocnemio semimembranosus (g s) bursa although he did not name it, and stated that it communicated with the joint in about 50% and more commonly in robust persons and especially in men He filled the communicating bursa by insufflating air into the joint through a patellar drill hole In a large number of dissections in children he never found a communication even though the *bursa was constantly observed not only in* newborn infants but also in foetuses In monkeys on the other hand he never saw this bursa He also described a separate hitherto unknown bursa beneath the upper most part of the gastrocnemius located above the femoral condyle which he named the bursa supracondyloidea (interna)' In his classic monograph Die Knieschleimbeutel (bursae mucosae genuales) he gave a detailed description of this bursa which did not communicate with the joint

Gruber considered that most of the communicating cavities were formed by synovial outpouching (Ausstulpung) whereas only one third were communicating bursae He also described and illustrated greatly varying and bizarre synovial protrusions through gaps in the gastrocnemius tendon and also the constriction of the neck which these protuberances sustained from such gaps Two of these illustrations are reproduced in Figure 3 Regarding the aforementioned giant cysts, he claimed that some did not communicate with the joint *cavity and thus constituted bursal hygromas* Gruber's concept of synovial protrusion has since been widely adopted in both the clinical and anatomical literature

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Poirier (1886) defended the concept of two separate bursae around the medial belly of the gastrocnemius even though they often coalesce He recognised that only this bursa could transform into a clinically manifest popliteal cyst and therefore designated it *bourse des kystes poplités* By injecting warm coloured suet he obtained casts of these bursae At their upper pole he discovered small processes (proces synoviaux sous condyliens) *He also pointed out the inti* mate connection between the bursal wall and the tendons and questioned whether even the most skilful surgeon could enucleate a popliteal cyst in its entirety

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association with popliteal cysts Not least it is interesting to note that a diligent survey of these papers and the illustrations given in them does not reveal any true hernial protrusion On the contrary all cases can be identified as originating from the communicating gastrocnemio semimembranosus bursa with the site of communication high up beneath the gastrocnemius tendon (Lindgren 1979) which is in agreement with the findings in a recent prospective arthrographic investigation of 41 popliteal cysts (Lindgren & Rauschning 1979) Regardless of whether popliteal cysts are considered to be synovial protrusions or distended bursae most surgeons state that the cyst has an attachment to the postero medial aspect of the knee joint capsule Occasional cases of communication with the joint in the central portion of the popliteal space and even communications situated beneath the posterior oblique ligament have been reported however (Haggart 1938)

Descriptions of the surgical anatomy are unspecific about the location and shape of the communication with the joint as well as about the topographic relationship to adjacent anatomical structures and opinions are greatly divided concerning the optimum surgical approach for exposure of the opening (Holmes 1870 Billroth 1876 Fullerton 1916 Davis 1918 Piersol 1919 Clark 1949 Wiles 1949 Anson & Maddock 1952 Lewin 1952 Apley 1968 Aegerter & Kirkpatrick 1975)

Reports have varied considerably concerning the *frequency of communication* as observed at operation In adults a frequency of more than 50% and up to 100% has been reported by surgeons who have published large materials (Hoffman 1963 58% Gristina & Wilson 1964 66% Bryan 1967 74% when a pathological condition of the joint was present 30% when it was absent Wilson et al 1938 98% Meyerding & van Demark 1943 100% Burleson et al 1956 65% Childress 1970 73% Vahvanen 1973 86%) Infantile popliteal cysts are commonly claimed to lack a communication with the joint (Morscher 1957 Malloch 1970 Borellini et al 1971) However Touloukian (1971) and Gristina & Wilson (1964) each found 11 communicating cysts at 20 and 23 operations respectively

In the opinion of some surgeons *closure of the communication* is unnecessary or not possible owing to the size of the opening (Moser 1950 Burleson et al 1956 Crasselt 1966 Justis 1971 Smillie 1974 Hort 1975) Most authors however apart from a radical excision of the cyst advocate closure of the communication (Bond 1890 Kirmisson 1892 Hawkes 1899 Hemet 1900 Wilson et al 1938 Edmunds & Hebble 1939 Meyerding & van Demark 1943 Haggart 1943 Kuhn & Hemphill 1944 Sachs & Rubinstein 1946 Orr 1951 Saegesser 1956 Kirpilä & Ripatti 1958 Beatty 1959 Harvey & Corcos 1960 Colombo 1965 Bryan et al 1967 Borellini et al 1971 Justis 1971 Solomon & Berman 1972 Goldstein & Dickerson 1974) Plastic aponeurotic procedures using free tendon grafts to close the opening in the capsule have been performed by Haggart (1938) and Childress (1954 1970)

In some larger reviews the results of *histopathological examination* of excised popliteal cysts have been reported (Hammer 1920 Haggart 1938 Wilson et al 1938 Buck et al 1943 Kuhn & Hemphill 1944 Burleson et al 1956 Kirpilä & Ripatti 1958 Harvey & Corcos 1960 Hoffman 1963 Myles 1971 Reinhardt 1972) but no consistent histological features have been described upon which a clinically relevant classification could be based or conclusions drawn regarding their pathogenesis

In the literature numerous accounts bear witness to the propensity of popliteal cysts to recur following surgical excision (Lewin 1952 Burleson et al 1956 Beatty 1959 Harvey & Corcos 1960 Hoffman 1963 Bryan et al 1967 Hooper & Brookler 1971 Myles 1971 Pinder 1973 Vahvanen 1973 Meire et al 1974) particularly after their removal in children (Malloch 1970 Dinham 1975) In a recent clinical and arthrographic follow up study Rauschning & Lindgren (1979) found 40 recurrences and 15 postoperative complications following 41 routine operations on such cysts

phic morphology of the communicating gastrocnemio semimembranosus bursa, using plaster of Paris to prepare the casts Corresponding radiographs and casts obtained during knee flexion and extension allowed an investigation of the functional radiographic anatomy of the bursa *Moser* (1950) undertook *dissection studies* and concluded that the communication between the joint cavity and bursa can result from violent hyperextension

Recently Lindgren & Willen (1977) performed post mortem arthrography, dissections, light microscopic and scanning electron microscopic investigations of postero medial knee capsule specimens from subjects of different age groups They demonstrated that the opening between the joint and the bursa constantly had the shape of a cranially oriented transverse slit in the joint capsule and that the gastrocnemio semimembranosus bursa more frequently communicated with the joint cavity with increasing age In older age groups they found degenerative changes in the capsular wall and also in the broad layer of fibroelastic tissue which in most young persons separates the joint from the bursa No essential morphological differences were noted between the synovial lining of the bursa and that of the joint but the degenerative changes in the bursa were more pronounced when it was in communication with the joint

RECENT INVESTIGATIONS ON POPLITEAL CYSTS (20th CENTURY)

Though the current opinion today tends towards the view that popliteal cysts develop from distension of a communicating knee bursa (Wilson et al 1938, Morscher 1957, Hoffman 1963, Gristina & Wilson 1964 Bryan et al 1967, Perri et al 1968, Goldstein & Dickerson 1974, Smillie 1974) the concept of a hernial origin still widely prevails (Cravener 1932 Haggart 1938 and 1943, Edmunds & Hebble 1939 Meyerding & van Demark 1943 Kuhn & Hemphill 1944 Sachs & Rubinstein 1946 Wiles 1949 Lewin 1952 Kirpilä & Ripatti 1958, Beatty 1959, Colombo 1965, Wieser et al 1967 Solomon & Berman 1972 Pinder 1973 Aegerter & Kirkpatrick 1975)

Other clinicians consider both modes of cyst formation possible (Burleson et al 1956 Ackerman 1959 Hoffman 1963 Justis 1971) The following is a list of some clinical synonyms of popliteal cysts which also provide an indication of the assumption concerning their mode of development

Baker s cyst Popliteal hernia Posterior herniation of the knee joint Kyste synovial herniaire Popliteal ganglion Arthrozele Popliteal synovial herniation Gastrocnemio semimembranosus bursa Medial gastrocnemius bursitis Semimembranosus bursa Semimembranosus bursitis Bursitis semimembranacea Semimembranaceuszysten Popliteal bursitis Intrapopliteal bursitis Zystische Bursitis, Synoviazyste Popliteazyste Poplitealzyste Popliteogene Unterschenkelzyste Bursal cysts Hygroma Zystisches bursales Hygrom Synoviales Kystom Cystic bursal hygromas Intermuscular synovial cysts

Lately comprehensive *arthrographic studies* of the posterior recesses of the knee and of the communicating popliteal cavities have been performed with the use of positive contrast medium and strong evidence in favour of the development of popliteal cysts from the communicating postero medial bursa has been produced (Ficat 1957 Kessler & Silberman 1960 Doppman 1965 Fischedick 1969 Lapayowker et al 1970 Fischedick 1971 Pallardy et al 1971, Reinhardt 1972 Solomon & Berman 1972 Wolfe & Coloft 1972 *Pulich 1975 Etienne et al* 1976 Lindgren 1977 Matthias 1977 Lindgren 1978) Many investigators point out the discrepancy between the radiographically high incidence of communicating bursae—which should not be called Baker s cysts as they are artificially distended (Rauschning & Lindgren 1979) —and the relative infrequency of clinically palpable popliteal cysts Arthrography has also proven of value for the diagnosis of intrinsic disorders of the knee which are frequently found in

association with popliteal cysts Not least it is interesting to note that a diligent survey of these papers and the illustrations given in them does not reveal any true hernial protrusion On the contrary all cases can be identified as originating from the communicating gastrocnemio semimembranosus bursa with the site of communication high up beneath the gastrocnemius tendon (Lindgren 1979) which is in agreement with the findings in a recent prospective arthrographic investigation of 41 popliteal cysts (Lindgren & Rauschning 1979) Regardless of whether popliteal cysts are considered to be synovial protrusions or distended bursae most surgeons state that the cyst has an attachment to the postero medial aspect of the knee joint capsule Occasional cases of communication with the joint in the central portion of the popliteal space and even communications situated beneath the posterior oblique ligament have been reported however (Haggart 1938)

Descriptions of the surgical anatomy are unspecific about the location and shape of the communication with the joint as well as about the topographic relationship to adjacent anatomical structures and opinions are greatly divided concerning the optimum surgical approach for exposure of the opening (Holmes 1870 Billroth 1876 Fullerton 1916 Davis 1918 Piersol 1919 Clark 1949 Wiles 1949 Anson & Maddock 1952 Lewin 1952 Apley 1968 Aegerter & Kirkpatrick 1975)

Reports have varied considerably concerning the *frequency of communication* as observed at operation In adults a frequency of more than 50% and up to 100% has been reported by surgeons who have published large materials (Hoffman 1963 58% Gristina & Wilson 1964 66% Bryan 1967 74% when a pathological condition of the joint was present 30% when it was absent Wilson et al 1938 98% Meyerding & van Demark 1943 100% Burleson et al 1956 65% Childress 1970 73% Vahvanen 1973 86%) Infantile popliteal cysts are commonly claimed to lack a communication with the joint (Morscher 1957 Malloch 1970 Borellini et al 1971) However Touloukian (1971) and Gristina & Wilson (1964) each found 11 communicating cysts at 20 and 23 operations respectively

In the opinion of some surgeons *closure of the communication* is unnecessary or not possible owing to the size of the opening (Moser 1950 Burleson et al 1956 Crasselt 1966 Justis 1971 Smillie 1974 Hort 1975) Most authors however apart from a radical excision of the cyst advocate closure of the communication (Bond 1890 Kirmisson 1892 Hawkes 1899 Hemet 1900 Wilson et al 1938 Edmunds & Hebble 1939 Meyerding & van Demark 1943 Haggart 1943 Kuhn & Hemphill 1944 Sachs & Rubinstein 1946 Orr 1951 Saegesser 1956 Kirpila & Ripatti 1958 Beatty 1959 Harvey & Corcos 1960 Colombo 1965 Bryan et al 1967 Borellini et al 1971 Justis 1971 Solomon & Berman 1972 Goldstein & Dickerson 1974) Plastic aponeurotic procedures using free tendon grafts to close the opening in the capsule have been performed by Haggart (1938) and Childress (1954 1970)

In some larger reviews the results of *histopathological examination of excised popliteal cysts* have been reported (Hammer 1920 Haggart 1938 Wilson et al 1938 Buck et al 1943 Kuhn & Hemphill 1944 Burleson et al 1956 Kirpilä & Ripatti 1958 Harvey & Corcos 1960 Hoffman 1963 Myles 1971 Reinhardt 1972) but no consistent histological features have been described upon which a clinically relevant classification could be based or conclusions drawn regarding their pathogenesis

In the literature numerous accounts bear witness to the propensity of popliteal cysts to recur following surgical excision (Lewin 1952 Burleson et al 1956 Beatty 1959 Harvey & Corcos 1960 Hoffman 1963 Bryan et al 1967 Hooper & Brookler 1971 Myles 1971 Pinder 1973 Vahvanen 1973 Meire et al 1974) particularly after their removal in children (Malloch 1970 Dinham 1975) In a recent clinical and arthrographic follow up study Rauschning & Lindgren (1979) found 40 recurrences and 15 postoperative complications following 41 routine operations on such cysts

phic morphology of the communicating gastrocnemio semimembranosus bursa, using plaster of Paris to prepare the casts Corresponding radiographs and casts obtained during knee flexion and extension allowed an investigation of the functional radiographic anatomy of the bursa *Moser* (1950) undertook dissection studies and concluded that the communication between the joint cavity and bursa can result from violent hyperextension

Recently Lindgren & Willen (1977) performed post mortem arthrography dissections light microscopic and scanning electron microscopic investigations of postero medial knee capsule specimens from subjects of different age groups They demonstrated that the opening between the joint and the bursa constantly had the shape of a cranially oriented transverse slit in the joint capsule and that the gastrocnemio semimembranosus bursa *more frequently* communicated with the joint cavity with increasing age In older age groups they found degenerative changes in the capsular wall and also in the broad layer of fibroelastic tissue which in most *young persons separates the joint from the* bursa No essential morphological differences were noted between the synovial lining of the bursa and that of the joint, but the degenerative changes in the bursa were more pronounced *when it was in communication* with the joint

RECENT INVESTIGATIONS ON POPLITEAL CYSTS (20th CENTURY)

Though the *current opinion today tends to* wards the view that popliteal cysts develop from distension of a communicating knee bursa (Wilson et al 1938 Morscher 1957 Hoffman 1963 Gristina & Wilson 1964 Bryan et al 1967 Perri et al 1968 Goldstein & Dickerson 1974 Smillie 1974) the concept of a hernial origin still widely prevails (Cravener 1932 Haggart 1938 and 1943, Edmunds & Hebble 1939 Meyerding & van Demark 1943 Kuhn & Hemphill 1944 Sachs & Rubinstein 1946 Wiles 1949 Lewin 1952 Kirpila & Ripatti 1958 Beatty 1959 Colombo 1965 Wieser et al 1967 Solomon & Berman 1972 Pinder 1973 Aegerter & Kirkpatrick 1975)

Other clinicians consider both modes of cyst formation possible (Burleson et al 1956 Ackerman 1959 Hoffman 1963 Justis 1971) The following is a list of some clinical synonyms of popliteal cysts which also provide an indication of the assumption concerning their mode of development

Baker s cyst Popliteal hernia Posterior herniation of the knee joint Kyste synovial herniaire Popliteal ganglion Arthrozele Popliteal synovial herniation Gastrocnemio semimembranosus bursa Medial gastrocnemius bursitis Semimembranosus bursa Semimembranosus bursitis Bursitis semimembranacea Semimembranaceuszysten Popliteal bursitis Intrapopliteal bursitis Zystische Bursitis, Synoviazyste Popliteazyste Poplitealzyste Popliteogene Unterschenkelzyste Bursal cysts Hygroma Zystisches bursales Hygrom Synoviales Kystom Cystic bursal hygromas Intermuscular synovial cysts

Lately comprehensive *arthrographic studies* of the posterior recesses of the knee and of the communicating popliteal cavities have been performed with the use of positive contrast medium and strong evidence in favour of the development of popliteal cysts from the communicating *postero medial* bursa has been produced, (Ficat 1957 Kessler & Silberman 1960 Doppman 1965 Fischedick 1969 Lapayowker et al 1970 Fischedick 1971 Pallardy et al 1971 Reinhardt 1972 Solomon & Berman 1972 Wolfe & Coloff 1972 Pulich 1975 Etienne et al 1976 Lindgren 1977 Matthias 1977 Lindgren 1978) Many investigators point out the discrepancy between the radiographically high incidence of communicating bursae—which should not be called Baker s cysts as they are artificially distended (Rauschning & Lindgren 1979) —and the relative infrequency of clinically palpable popliteal cysts Arthrography has also proven of value for the diagnosis of intrinsic disorders of the knee which are frequently found in

ANATOMICAL NOMENCLATURE AND SELECTED SYNONYMS

I Bursa subtendinea musculi gastrocnemii medialis (I A N C)

= Bursa musculi gastrocnemii medialis (B N A)
= Bursa capitis tibialis musculi gastrocnemii (J N A)
= Bursa subtendinea musculi gastrocnemii medialis (P N A)

= Bursa mucosa supracondyloidea (interna) (GRUBER 1857)
= Bursa mucosa capitis interni gastrocnemii (HEINEKE 1868)
= Bourse sereuse rétro-condylienne superieure ou du jumeau interne (POIRIER 1886)
= Bourse sereuse de muscle jumeau interne (TILLAUX 189?)
= Bursa gastrocnemia medialis (FICK 1904)
= Bourse du jumeau interne (TESTUT 1909)

II (Bursa gastrocnemio semimembranosa not designated in **I A N C)**

= Bursa gastrocnemio semimembranosa (B N A)
= Bursa gastrocnemio semimembranacea (J N A)
= Bursa gastrocnemiosemimembranosa (P N A)

= Bursa mucosa retro-condyloidea interna sive semimembranoso-gastrocnemialis (GRUBER 1857)
= Bursa mucosa semimembranoso-gastrocnemialis (SYNNESTVEDT 1869)
= Bursa synovialis semimembranosa (HENLE 1871)
= Bourse retro-condylienne inferieure ou bourse commune au jumeau interne et au demimembraneux (POIRIER 1886)
= Bourse des kystes poplités (POIRIER 1886)
= Bursa gastrocnemio-semimembranosa retrocondylica medialis (FICK 1904)

III Bursa musculi semimembranosi (I A N C)

= Bursa musculi semimembranosi (B N A)
= Bursa musculi semimembranacei (J N A)
= Bursa musculi semimembranosi (P N A)

= Bursa parva (ALBINUS 1734)
= Bursa mucosa infra-condyloidea interna sive semimembranosa (GRUBER 1857)
= Bourse séreuse sous-condylienne (POIRIER 1886)
= Bourse sereuse du tendon direct du muscle demimembraneux (TILLAUX 189?)
= Bursa semimembranosa (FICK 1904)
= Bursa semimembranosa propria sive tibio-semimembranosa (MERKEL 1907)
= Bourse propre du démi membraneux (TESTUT 1909)

The bursa around the medial head of the gastrocnemius (II) has also been referred to as the bursa magna (ALBINUS 1734) bursa vesicularis postica ad latus genu (MONRO 1788) and bursa genualis posterior (ROSENMÜLLER 1799) These investigators did not mention the bursa beneath the medial head of the gastrocnemius muscle (I)

AIMS OF THE PRESENT INVESTIGATION

Concerning the surgical anatomy of popliteal cysts the reader both of papers dealing with this subject and of recognised textbooks of anatomy and orthopaedic surgery meets with information that is inconsistent in several respects The aim of the present investigation was therefore to study

1 the origin of popliteal cysts, in order to establish whether they are capsular herniations or fluid distended bursae
2 the optimum surgical approach to the cyst particularly its communication with the joint
3 the topographic anatomy of the deep portion of the cyst commonly referred to as its neck pedicle or stalk
4 the possibility and necessity of isolating the whole cyst,
5 the possibility and necessity of radical removal of all cyst tissue,
6 the detailed anatomy of the communication with respect to its location, shape and width,
7 the frequency of communication of popliteal cysts as observed during operation,
8 the presence of any weak portions in the postero medial knee joint capsule
9 the implications of the joint movement of tendon pull and of possible capsular tearing forces for the surgical technique
10 the anatomical prerequisites for achieving a firm and durable closure of the communication

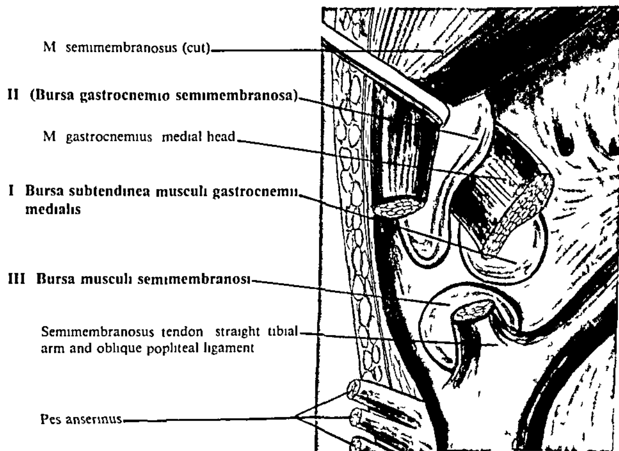


Figure 4 The location of the three knee bursae under study and their current denomination according to the International Anatomical Nomenclature Committee (1966)

ANATOMICAL NOMENCLATURE AND SELECTED SYNONYMS

I Bursa subtendinea musculi gastrocnemii medialis (I A N C)

≈ Bursa musculi gastrocnemii medialis (B N A)
≈ Bursa capitis tibialis musculi gastrocnemii (J N A)
≈ Bursa subtendinea musculi gastrocnemii medialis (P N A)

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= Bursa mucosa cap tis interni gastrocnemii (HEINEKE 1868)
= *Bourse séreuse retro-condylienne superieure ou du jumeau interne* (POIRIER 1886)
= Bourse séreuse de muscle jumeau interne (TILLAUX 189?)
= Bursa gastrocnemia medialis (FICK 1904)
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= Bursa gastrocnemio semimembranacea (J N A)
= Bursa gastrocnemiosemimembranosa (P N A)

– Bursa mucosa retro-condyloid a interna sive semimembranoso-gastrocnemialis (GRUBER 1857)
– Bursa mucosa semimembranoso-gastrocnemialis (SYNNESTVEDT 1869)
= *Bursa synovialis semimembranosa* (HENLE 1871)
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= Bourse des kystes poplites (POIRIER 1886)
= Bursa gastrocnemio-semimembranosa retrocondylica medialis (FICK 1904)

III Bursa musculi semimembranosi (I A N C)

= Bursa musculi semimembranosi (B N A)
= Bursa musculi semimembranacei (J N A)
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= *Bursa par a* (ALBINUS 1734)
= Bursa mucosa *infra-condyloidea interna sive semimembranosa* (GRUBER 1857)
= Bourse séreuse sous-condylienne (POIRIER 1886)
Bourse sereuse du tendon d rect du muscle demimembraneux (TILLAUX 1892)
= Bursa semimembranosa (FICK 1904)
= *Bursa semimembranosa propria* si e t bio-semimembranosa (MERKEL 1907)
= Bourse propre du démi-membraneux (TESTUT 1909)

The bursa around the medial head of the gastrocnemius (II) has also been referred to as the bursa magna (ALBINUS 1734) bursa vesicularis postica ad latus genu (MONRO 1788) and bursa genualis posterior (ROSENMÜLLER 1799) These investigators did not mention the bursa beneath the medial head of the gastrocnemius muscle (I)

ANATOMICAL DISSECTION STUDY

Conventional knife dissections were conducted on human cadavers to clarify the detailed anatomy of the g.-s. bursa and the location of its communication with the joint. During these dissections observations were also made concerning capsular tearing forces that might be transmitted to the capsular opening. The surgical approach was studied with particular reference to the access to the communication and to the avoidance of damage to cutaneous nerves.

MATERIAL

The material was obtained from autopsies at the Department of Pathology, University of Uppsala, in the years 1977 and 1978. The knees of 200 cadavers were examined by palpation and in no case was a cystic swelling palpable in the popliteal space. Among these 200 cases 54 were chosen for whom a study of the medical records and physical examination revealed no history or signs of rheumatoid arthritis affecting the knee, effusion into the knee joint, or previous knee operations. Cardiovascular disorders were the most common cause of death. The material thus consisted of 108 non-diseased joints. Eight subjects were 40—50 years of age at the time of death and 46 were 51 years of age or older. Thirty five knees were from men and 19 from women.



Figure 5. Oblique medial view of a right knee in an autopsy case in the prone position. Thigh to the left, lower leg to the right. After resection of the bursa a plastic band was inserted from the site of the commonly used incision centred over the swelling to demonstrate the conventional path of surgical approach to the communication. The decussation of the tendons obstructs the access to the opening in the capsule beneath the gastrocnemius (gc) (interrupted line). sm = semimembranosus, st = semitendinosus, g = gracilis, sa = sartorius, pa = pes anserinus.

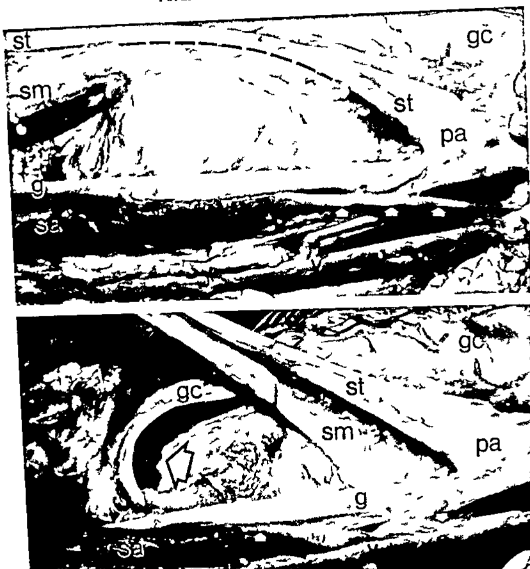


Figure 6 *Medial view of a right knee in an autopsy case in the prone position For abbreviations see Figure 5 The saphenous nerve (small arrows) conjoints with the great saphenous vein (v)*

Upper *The dashed line indicates the incision suggested by the author (extended knee) The [illegible] serves as a landmark*

Lower *Upon knee flexion the tendons are easily retracted dorsally providing good access to the [illegible] of the capsule (large arrow)*

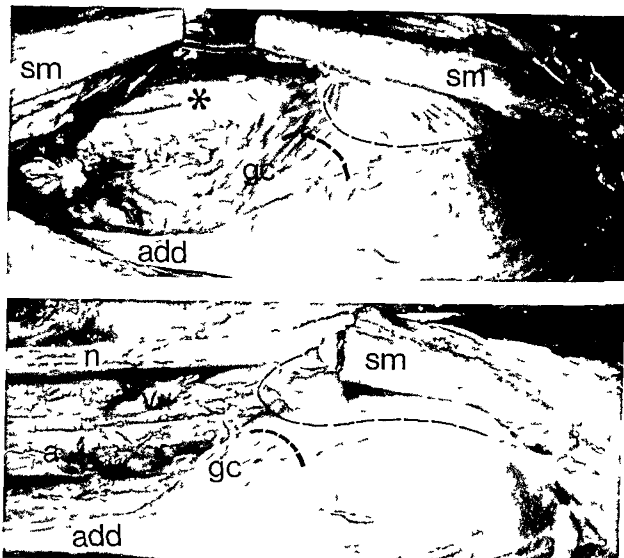


Figure 7 Medial view of a right knee in an autopsy case in the prone position The pes anserinus tendons have been removed The g s bursa bulges beneath the semimembranosus (sm) There is no anatomical obstacle between the bursa and the neurovascular structures (*) The adductor magnus (add) and gastrocnemius (gc) are intimately inter woven Resection of the semimembranosus (lower figure) gives a free view of the popliteal artery (a) vein (v) and nerve (n) The thick dashed line indicates the site of the communication between the joint and the bursa beneath the gastrocnemius tendon

SELECTION OF SPECIMENS AND COURSE OF DISSECTION

All 108 knees were filled with 60—80 ml of saline tinted with methylene blue With the body in the prone position the popliteal fascia was exposed and incised longitudinally along the lateral border of the semitendinosus tendon Upon repeated gentle flexion communicating cysts filled in 58 knees (13 right 9 left and 18 bilateral) on several occasions with an audible and palpable bruit These were submitted to detailed dissection In all 108 knees the entire posteromedial capsule was transilluminated with fibreoptic light in search for any weak areas

The subcutaneous nerves at the posteromedial aspect of the knee were dissected the course of the major saphenous nerve in particular The bursae artificially distended with fluid were dissected to clarify the extent of the bursa its gross anatomy and its topographic relationship to the structures of this region The site of the communication was determined in relation to the origin of the

gastrocnemius tendon The size and shape of the opening was recorded and the deformation of the opening caused by passive movement of the knee as well as by pull on inserting tendons simulating *active flexion* was examined Finally the thickness of the gastrocnemius tendon overlying the capsular aperture was measu ed at three levels

CUTANEOUS NERVES

The *saphenous nerve* after passing through the subsartorial canal was invariably found *to emerge between the sartorius muscle and* the gracilis tendon It entered the subcutaneous space by *perforating* the crural *fascia* above or at the level of the joint As a rule the nerve joined the great *saphenous vein within a few centimetres (Figures 5 and 6)* Accessory branches were present in two *cases* and in one *further specimen* an extra fascial anatomosis with the cutaneous nerve ending of the *anterior* division of the obturator nerve was observed The average distance between the saphenous nerve and the medial border of the gastrocnemius *tendon* at the level of the femoral condyle was 4 cm (*range* 3—6 cm) The centre of the popliteal region *was supplied by terminal branches of the posterior femoral cutaneous nerve* The number and distribution of nerve endings *varied considerably but the saphenous nerve* and its branches were oriented in the longitudinal *axis of the leg Occasionally fibres* from the posterior femoral cutaneous nerve crossed the cyst beneath the popliteal fascia without sending branches to its wall



Figure 8 Extraarticular view of the communication in the right knee of an a topsy case in the prone position Seen from the med o-distal direction The gas rocnemius (gc) is retra ed dorsally The loose part of the bursal wall has been resected and the remainder a heres f rmly to the capsule and the tendons A probe is inserted beneath the lo e capsular port on Note the ma ked th nning of the capsule dist l t the sharp u per ma gin The femoral condyle (c) is visible through the b sm semimembranosus en on

THE COMMUNICATING BURSA

Of the six primary bursae at the postero medial aspect of the knee (Wilson et al 1938) only the g s bursa was found to communicate with the knee joint After division of the unyielding popliteal fascia this bursa was invariably found in the sulcus formed by the muscle bellies of the semimembranosus and medial head of the gastrocnemius, the so called sulcus popliteus medialis It was oblong or ovoid 1—2 cm wide and 3—6 cm long (Figure 7) Its posterior wall was usually slightly lobulated and surrounded by loose areolar tissue No communication with the semitendinosus tendon sheath was seen The lower pole was usually firmly attached to the medial border of the gastrocnemius by a fibrous cord Once this was divided the bursa could easily be dissected free Towards the decussation of the gastrocnemius and semimembranosus tendons the bursal wall became increasingly adherent As, during knee extension, these tendons were forcefully pressed against each other, flexion of the knee and retraction of the muscles was required to obtain access to the anterior compartments of the bursa (Figures 5 and 6) One constant process of the bursa was situated between the joint capsule and the straight tibial arm of the semimembranosus tendon and occasionally protruded medially (Figure 7) Another compartment of the compound g s bursa consisted of the constant bursa beneath the tendon of the gastrocnemius muscle In 54 cases this bursa had coalesced with the above mentioned bursa between the gastrocnemius and semimembranosus tendons (Figure 8) In four specimens only the small subgastrocnemius bursa *filled with fluid from within the joint* while the bursa between the tendons of the gastrocnemius and semimembranosus was empty

Membranes were frequently found within the g s bursa They formed incomplete septa usually oriented in the sagittal plane Some of the larger g s bursae extended in the cranial direction beneath the semimembranosus tendon and this portion in particular frequently displayed diverticulae Small branches of the medial superior genicular artery entered the bursa at its upper pole The inner surface of the bursa was often covered with soft synovial ridges Sometimes diverticulae or meshwork of tiny synovial bands were seen especially in the anterior portion Fibrin or mucin clots as well as cartilage debris and a few rice bodies were contained in some of the bursae

THE COMMUNICATION

In all specimens transillumination disclosed a thin area in the postero medial capsule immediately distal to the 2 5—3 cm broad gastrocnemius tendon insertion (Figures 8 and 9) No such thinning was seen around the oblique popliteal ligament When the bursa communicated with the joint cavity the opening presented as a transverse slit at the uppermost rim of the capsule separating the capsule from the gastrocnemius tendon opposing the upper lateral circumference of the femoral condyle Its width was 4—24 mm (mean 1 8 mm) The margin was sharply defined and occasionally slightly frayed The slit was situated 2 0—5 5 cm (mean 3 4 cm) distal to the origin of the gastrocnemius tendon From the inside of the joint it resembled the pouch of a kangaroo (Figure 9) The slit invariably lay over the postero lateral circumference of the medial femoral condyle thus facing the centre of the popliteal fossa (Figure 7 interrupted line) and was separated from the popliteal nerve and vessels by the broad gastrocnemius muscle belly (Figure 8)

The entire capsular opening was covered by the tendon of the gastrocnemius muscle Opposite the medial edge of the slit it was



Figure 9 Preparation of the postero-medial capsule remo ed in a fro en state from the left knee of an autopsy speci men

Left *Intraarticular view showing the meniscus at the bottom and the slit shaped communication between the joint cavity and the bursa at the top*

Upper right *Detail of the communication Behind the broad gap the gastrocnemius tendon (gc) is seen*

Lower right *The opening viewed from above after hori ontal section of the gastrocnemius tendon*

3—7 mm thick (mean 4 8 mm) opposite the mid point of the slit 3—7 mm (mean 4 6 mm) and at the the lateral edge 3—6 mm (mean 3 9 mm) (Figure 9) In three cases a *tiny synovial ridge was detected on the arti* cular surface of the gastrocnemius tendon whereas no counterpart for the sharp upper rim of the capsule was seen in the remaind r of specimens

When the tibia was rotated at various degrees of knee flexion the slit was defor med diagonally Pulling on the semimembra nosus tendon particularly with the knee flexed markedly widened the opening cranio-caudally On several occasions the slit *widened owing to further tearing at its edges* Simulated hyperextension did not widen the gap as the capsule was pulled cranially by the semimembranosus tendon which then acted as a tension band protecting the capsu lar opening

SERIAL CRYOSECTIONING OF UNDECALCIFIED SPECIMENS

A substantial drawback of conventional knife dissection is the increasing difficulty in orientation encountered in the preparative procedure Thus when the fascia is split the popliteal space pressure decreases and the collapse of the cyst after escape of its fluid content together with the distortion result ing from retraction and division of tendons and muscles make determination of the to pography and the dimensions of the cyst dif ficult The rather complex pluricompart mental extensions of the bursa and its rela tionship to the tendons which it covers, are difficult to visualize Moreover the displace ment and compression of popliteal structures caused by a distended cyst are relieved once the fluid filled cavity is emptied

Ullberg and co workers (1954 1977) deve loped a procedure of cryosectioning of whole animals for autoradiographic and toxicolo gical studies As serial sectioning of the fluid filled frozen joint would permit a de tailed study of the synovial extension of the articular cavity and the bursa, the technique of cryosectioning of large animal specimens was modified A description and discussion of the technique is also given elsewhere (Rauschning 1979)



Figure 10 Sagittal cryosection through the medial posterior portion of an amputation knee specimen fro en in slight flexion The g s bursa does not communicate with the joint cavity It is seen as a thick dark line between the tendons of the gastrocnemius (gc) and the semimembranosus (sm) which are twisted around each other in the same sagittal plane The arrow indicates the junction between the capsule and the gastrocnemius tendon

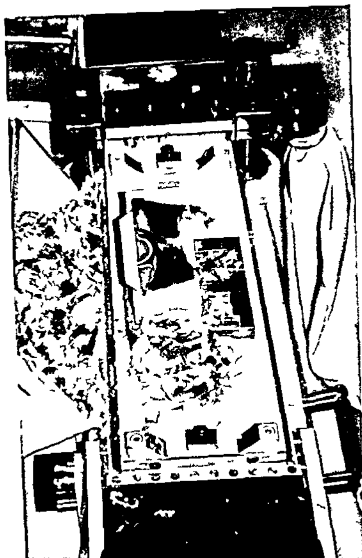


Figure 11 Serial cryosectioning with a heavy duty cryomicrotome built into a cryostat (LKB 2250 PMV) A human knee jo nt specimen with a communicating popl teal bursa is sectioned in the sagittal plane at —20°C The block is mounted on the hori ontally moving sledge and the knife is fed downwards to cut sections 5—200 µm thick The debris can be removed by a vacuum cleaner during automatic trimming

MATERIAL AND METHODS

The material consisted of 14 fresh human knee joints Two knees were obtained from above knee amputations for arteriosclerotic gangrene These two amputated knees had no communicating g s bursa one was sec tioned in the horizontal and the other in the sagittal plane (Figure 10) The remaining specimens were obtained at autopsies The subjects were over 50 years of age and all knees were healthy and had not been ope rated upon The presence of a communicat ing bursa in the autopsy cases was ascer tained as follows With the body in a prone position 60—80 ml of methylene blue stained water was instilled into the joint and the popliteal fascia was exposed by raising a large rectangular skin flap When at gentle



Figure 12 (×1 5 The knee specimens were fro en at moderate flexion the dashed line in the upper figure indicates the plane of sectioning in the lower figure and vice versa

Upper *Sagittal cryosection at the medial border of the communication A large communicating g s bursa displaces the gastrocnemius (gc) laterally and the semimembranosus (sm) medially i e towards the viewer Note the broad insertion of the semimembranosus in the tibia*

Lower *Hori ontal cryosection at the level of the thin upper rim of the capsule The thick gastrocnemius tendon covers the capsular slit Note the septa in the bursa*



Figure 13 (×4 Same specimens as in Figure 12)

Upper *Detail from a sagittal cryosection some mms medial to the slit formed communication A synovial fold conjoins the capsule with the gastrocnemius tendon (gc)*

Lower *Detail from a hori ontal cryosection through the upper postero medial recess of the knee The origin of the gastrocnemius forms a broad tendinous cupole no separate fibrous capsule is seen*



Figure 12 (×1 5 *The knee specimens were fro en at moderate flexion the dashed line in the upper figure indicates the plane of sectioning in the lower figure and vice versa*

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Lower *Detail from a hori ontal cryosection through the upper postero-medial recess of the knee The origin of the gastrocnemius forms a broad tendinous cupole no separate fibrous capsule is seen*

flexion a communicating cyst could be seen through the fascia carbon dioxide snow was repeatedly applied between the skin flap and the fascia It took approximately six hours for the knee to become frozen Thus 12 cadaver knees with communicating g s bursae were obtained In one case with bilateral communicating bursae one knee was frozen at maximal extension and the other at about 40° of flexion The remaining 10 knees were frozen at various angles of flexion A block was then cut comprising either the whole popliteal space, including the posterior halves of the femoral condyles and the tibial plateau, or—for sagittal plane sectioning—the postero medial quadrant of the joint containing a larger portion of the medial femoral and tibial condyles

Specimens with a maximum height of about 7 cm were mounted on a large stage, in a semiliquid solution of carboxymethyl cellulose (CMC gel) and then frozen in a container filled with hexane cooled with dry ice to a temperature of about —75°C The freezing time was 20—30 minutes

The block was placed in a plastic bag and stored in a freezer (—25°C) Prior to sectioning the block was left in the microtome cryostat for some hours for thermal equilibration (—20°C) Cracking of the surface was observed if the block was not allowed to accommodate

The specimen was mounted on the sledge of a heavy duty microtome (LKB 2250 PMV Cryo Microtome) The whole frozen specimen was sectioned through and the surface of the block was photographed by the author at consecutive levels (Figure 11)

It was not necessary to collect sections on tape since the anatomical details were well outlined by their natural colours on the surface of the block Also the methylene blue stained ice contained in the articular cavities showed up with good contrast The brilliance of the picture was improved if the surface of the block was thawed by rubbing it with a cloth soaked in ethylene glycol

As the control panel of the cryomicrotome could be programmed to cut a predetermined number of sections (1—20) of selected thickness equidistant intervals for documentation were ensured The maximum microtome knife excursion of 50 mm was increased to approximately 65 mm by intermounting an additional bottom plate More than 1,000 sections were cut from every specimen Ten specimens were sectioned in the transverse plane and four in the sagittal plane

For photography a 35 mm SLR camera equipped with a 50 mm macro lens and an automatic flash was used and photographs were taken on 25 ASA colour film with a gauge placed on the block The magnification on the film could be read directly on the scale of the lens As a rule photographs were taken at 2 mm intervals The films were studied at intermediate magnification in a light microscope or by projection onto a screen

RESULTS

The tendon of the medial head of the gastrocnemius took the shape of a broad plate and originated from the supracondyloid tubercle and along a crest extending towards the insertion of the adductor magnus tendon Here both tendons were intimately interwoven The muscular portion arose from an area of roughened bone on the popliteal aspect of the femoral shaft The ratio of the muscular to the tendinous portions varied greatly The gastrocnemius tendon covered the lateral half of the posterior curvature of the medial femoral condyle forming a 4—8 mm thick dome The tendon alone constituted the upper part of the fibrous capsule All fibres were oriented longitudinally and no separate layer of capsular fibres was detected (Figures 12—15) Towards the centre of the popliteal space the muscular portion increased The slit shaped opening into the joint was always completely covered by the tendon (Figures 12 and 15) No sesamoid bone or cartilage was found The neurovascular supply to the muscle was seen on the lateral aspect of the muscle belly below the level of the joint

The straight tibial arm of the semimembranosus tendon had a very broad insertion in the tibia (Figure 12) In both sagittal and horizontal sections the oblique popliteal ligament presented as a diffuse thickening of the fibrous capsule (Figures 12 and 14) Neither above nor below this posterior oblique ligament was any weakening of the capsule detected The posterior horn of the medial meniscus was not firmly attached to this particular portion of the capsule whereas its postero medial and medial segments were closely interwoven with the capsule the attachment increasing in the medial direction (Figures 12 and 14)

The thick capsular portion above the oblique popliteal ligament consisted of transversally and diagonally oriented fibrous strands Towards the junction with the gastrocnemius its thickness decreased almost abruptly and this thin area in the frontal plane was always narrower than the overlying tendon The medial and lateral borders of this capsular window consisted of longitudinally oriented fibrous columns No fibrous margin corresponding to the sharply defined rim of the capsule was seen on the articular surface of the gastrocnemius tendon and in no specimen could the former line of attachment be identified Some thin synovial bands but no membranes partially bridged the orifice (Figure 12)

With the knee in extension the popliteal artery vein and nerve lay close to the medial aspect of the lateral femoral condyle During flexion the neurovascular structures retracted away from the capsule posteriorly The broad medial belly of the gastrocnemius muscle was interposed between the site of the capsular opening and the blood vessels and nerves

The communicating g s bursa extended between the tendons of the gastrocnemius and the semimembranosus In one case however only the subgastrocnemial bursa was filled with blue ice When the bursa was distended it displaced the gastrocnemius tendon laterally and the semimembranosus tendon medially (Figure 12)

In knees frozen in flexion the posterior joint recesses and the anterior extensions of the g s bursa were wide and filled with ice and the capsular gap was open (Figures 14 and 15)

During knee extension both the posterior recesses and the subgastrocnemial portion of the bursa were completely emptied and were only discernible as thin blue lines The gastrocnemius tendon was firmly stretched over the condyle thus compressing the capsular slit The tightly overlying semimembranosus tendon seemed to potentiate this effect (Figure 16) The posterior portion of the bursa bulged beneath the popliteal fascia

Strikingly often the bursal cavities were subdivided by membranes and septa which were not oriented in any particular direction As all compartments of the cyst were filled with methylene blue stained ice however they must have been incomplete or perforated (Figures 12—15) The wall of the posterior portion of the bursa was well defined In the deep compartments no separate fibrous wall was seen A synovial lining intimately followed the tendons the aponeuroses of the muscles and the capsule and no plane of cleavage was detected

flexion a communicating cyst could be seen through the fascia carbon dioxide snow was repeatedly applied between the skin flap and the fascia It took approximately six hours for the knee to become frozen Thus 12 cadaver knees with communicating g s bursae were obtained In one case with bilateral communicating bursae one knee was frozen at maximal extension and the other at about 40° of flexion The remaining 10 knees were frozen at various angles of flexion A block was then cut comprising either the whole popliteal space, including the posterior halves of the femoral condyles and the tibial plateau or—for sagittal plane sectioning—the postero medial quadrant of the joint containing a larger portion of the medial femoral and tibial condyles

Specimens with a maximum height of about 7 cm were mounted on a large stage in a semiliquid solution of carboxymethyl cellulose (CMC gel) and then frozen in a container filled with hexane cooled with dry ice to a temperature of about —75°C The freezing time was 20—30 minutes

The block was placed in a plastic bag and stored in a freezer (—25°C) Prior to sectioning the block was left in the microtome cryostat for some hours for thermal equilibration (—20°C) Cracking of the surface was observed if the block was not allowed to accommodate

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Figure 14 *(×2 Same specimens as in Figure 12)*

Upper *Sagittal cryosection at the level of the lateral portion of the communi cation The g s bursa causes an impression in the gastrocnemius (gc) which at this level mainly consists of muscular tissue Note the loose connection between the meniscus and the oblique popliteal ligament ( )*

Lower *Hori ontal cryosection about 1 cm distal to the upper margin of the capsule The bursa is interposed between the capsule the semimembra nosus (sm) and the gastrocnemius tendon (gc)*



Figure 15 *(×4 Same specimens as in Figure 12)*

Upper *Detail from a sagittal cryosection through the mid portion of the slit*

Lower *Detail from a hori ontal cryosection at the level of the sharp upper rim of the capsule (cf Figure 12) The tendinous origin of the gastrocnemi us (gc) covers the communication with some overlapping*



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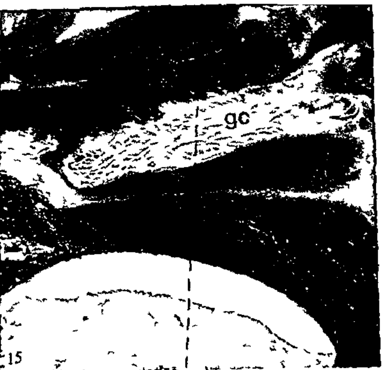


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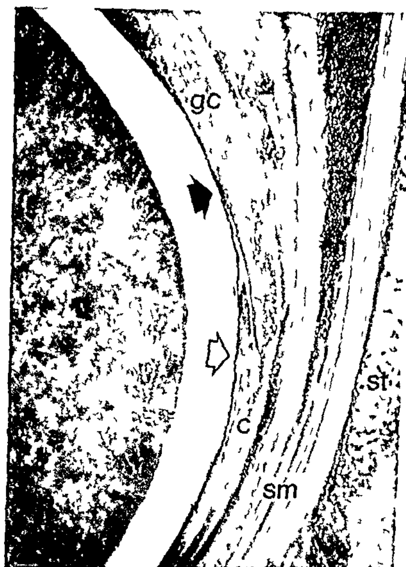


Figure 16 Sagittal cryosection through the postero medial quadrant of an autopsy knee specimen at the level of the mid portion of the slit the knee was frozen at maximal extension (cf Figure 3) The gastrocnemius tendon (gc) constitutes the upper fibrous capsule the lower capsular portion (c) displays thinning at a length of 2 cm (indicated by arrows the filled arrow indicating the upper margin of the capsule) The semimembranosus (sm) and semitendinosus (st) firmly compress the capsule emptying all fluid from the joint recess and the anterior portions of the bursa

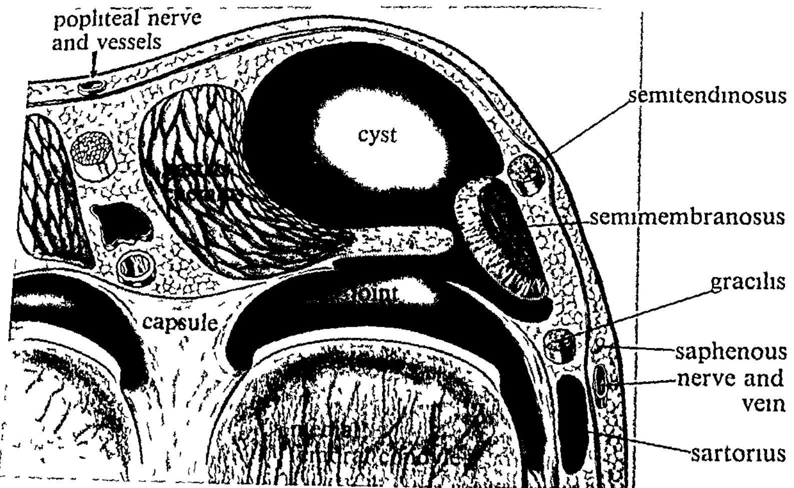


Figure 17 The surgical anatomy of popliteal cysts illustrated in a semi schematic horizontal cross section of the postero-medial quadrant of the knee at the level of the communication with the popliteal cyst

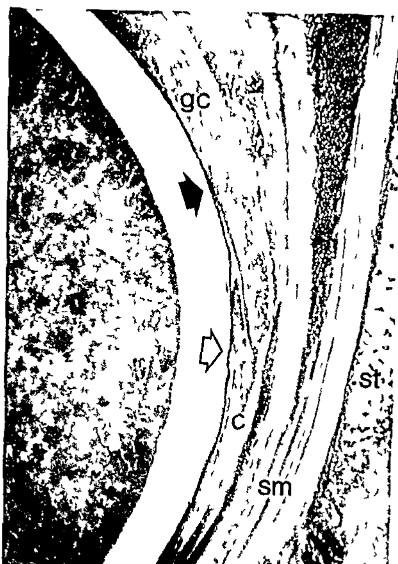


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Figure 18 Intraoperative view of the communication between the joint and the popliteal cyst (medial view of the right knee with the patient lying supine and the gastrocnemius tendon (gc) dorsally retracted) Membranes are concealing the opening After removal of one membrane (left) another septum with a round hole at its medial border appeared (right) At preoperative arthrography contrast medium had passed from the joint to the bursa but could not be manipulated back into the joint (valve mechanism)

DISCUSSION

Although the *aetiology and pathogenesis* of popliteal cyst formation are still a matter of debate the present investigation has provided overwhelming evidence that at least in the great majority of instances they arise from the gastrocnemio semimembranosus bursa In the present study all clinically significant popliteal cysts consisted of distended bursae Concerning the reports of early authors who from dissection studies of amputated limbs or from examination of cadavers with large popliteal cysts concluded that the cysts had formed by a hernial protrusion of the synovial membrane through gaps in the fibrous capsule it should be pointed out that many of the knees were severely affected by tuberculosis with far advanced derangement of the joint capsule (Gruber 1846 1869 Powers 1897) It may also be attributable to the virtual absence of joint tuberculosis that other investigators and I myself have failed to detect any popliteal cyst on palpation of a large number of cadavers whereas quite a number of cysts have been reported in the early literature (see Introduction)

At operation on popliteal cysts of the present study *synovial membranes* were found in the upper subgastrocnemial portion of the cysts in 50% of the cases concealing the communication but not impeding the flow of synovial fluid from the joint into the cyst Once these were removed the normal slit shaped capsular opening of the g s bursa came into view These membranes presumably provide a plausible explanation for the numerous operative observations of seemingly non-communicating popliteal cysts which at preoperative arthrography had nevertheless filled with contrast medium from the joint (Burleson et al 1956 Hoffman 1963 Gristina & Wilson 1964 Bryan 1967 Childress 1970)

INTRAOPERATIVE MORPHOLOGY OF POPLITEAL CYSTS

PATIENTS AND METHODS

Observations made in the course of 26 operations on popliteal cysts, all performed by the author were analysed The mean age of the *patients was 44 6 years (range 19—69 years)* To diagnose suspected associated knee disorders arthrotomy was performed in five knees and arthroscopy in 10 knees One rupture of the medial semilunar cartilage two cases of rheumatoid arthritis, one synovitis of uncertain origin, eight cases of advanced osteoarthritis and seven cases of chondromalacia of the patella or the femoral condyles *were diagnosed One meniscectomy two* synovectomies and two advancements of the tibial tuberosity had been performed at the same session as the operation on the cyst Two of the operations were for recurrent cysts

RESULTS

At operation all popliteal cysts were confined to the medial popliteal region and identified as g s bursae from their location and their anatomical relationship to the joint capsule and the above mentioned tendons and from the site of communication between *the cyst and the knee joint Only the findings* at operation which differed noteworthily from those made on the bursa at dissection described above will therefore be reported

Five cysts were about the size of the normal g s bursa, 13 were about as large as a hen's egg and seven were considerably larger, one (in a rheumatoid knee) was a giant popliteal cyst In large cysts the posterior portion was flattened by the coarse popliteal fascia forcing the cyst to extend craniolaterally *towards the neurovascular structures* posterior to the gastrocnemius muscle No cyst bulged towards the centre of the popliteal space *beneath* the gastrocnemius muscle Incision of the deep fascia obviously relieved the pressure in the popliteal space as the cyst assumed a rounded shape and protruded through the fascial gap In most cases the posterior portion of the cyst was easily isolated by blunt dissection but some cysts with a thicker wall were firmly adherent *to the surrounding tissues* Anteriorly all cysts firmly adhered to the tendinous portions of the muscles It was not possible to dissect the cyst wall from these tendons or the capsule In one case the cyst extended as far as the adductor magnus tendon

Fifteen cysts contained synovial fluid of low viscosity and the remainder more viscous fluid In five cases the fluid had a gelatinous appearance Osteocartilaginous loose bodies were found in two cysts The inner surface of the cysts was covered by far *thicker and coarser ridges membranes* and septa than in the normal bursa and diverticulae were numerous

The communication was invariably located beneath the tendon of the medial head of the gastrocnemius muscle In Figure 17 the surgical anatomy is illustrated in a semischematic horizontal cross section

The capsular opening in 13 cases had the same shape and size as those found in the anatomical dissection study In five cases *thin septa and synovial bands* concealed the major part of the orifice and in eight cases no opening was found although saline instilled into the joint at flexion readily appeared at the site where the communication is usually located As the operation proceeded it became apparent that membranes with marginal slit shaped apertures covered the communication (Figure 18) Several membranes with openings at various sites were common When these membranes were removed the usual bursal communication slit became visible *In one* knee no communication was found even though a communicating g s bursa had been demonstrated at preoperative arthrography The opening was now completely obliterated by synovial bands and membranes



Figure 18 Intraoperative view of the communication between the joint and the popliteal cyst (medial view of the right knee with the patient lying supine and the gastrocnemius tendon (gc) dorsally retracted) Membranes are concealing the opening After removal of one membrane (left) another septum with a round hole at its medial border appeared (right) At preoperative arthrography contrast medium had passed from the joint to th bursa but could not be manipulated back into the joint (valve mechanism)

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The apparent discrepancy between the uniform shape of the communication in the present series of operations and the wide variety of shapes and sizes of the apertures as reported by many surgeons, may be due to the great diversity that is observed in the openings in the membranes It is obvious that closure of the aperture in such membranes will hardly result in a tight seal when the concealed underlying capsular opening is left untouched

In the clinical material of the present study a *valve mechanism* was demonstrated at the site of communication in 10 of the knees preoperatively by means of a specific arthrographic technique (Lindgren & Rauschning) In these cases contrast medium from the joint cavity readily passed over to the cyst while no passage in the opposite direction occurred when the cyst was manually compressed As membranes and synovial folds were found at operation in these cases, it is conceivable that they constitute the pathoanatomical basis of the valve mechanism

Cryosectioning of undecalcified specimens frozen *in situ* and then removed as modified to suit the purpose of this study allowed an examination of the true and undistorted anatomy of the ice filled joint and bursa and the relation of the bursa to the capsule and tendons As no artifacts such as may result from conventional histological procedures occurred the sections reflected the true interrelationship of structures at each particular level The filling of the synovial cavities with coloured water was helpful in delineating the extensions of the bursa as the synovial membrane was tinted blue No difficulties were encountered in sectioning the bone not even the cortical bone in the metaphysis The image obtained from the rubbed surface of the block displayed natural colours making it easy to recognise and interpret the individual structures By observing the variations of fluid filling of the different compartments of the bursa in different positions of the knee the functional anatomy could be examined in a frozen state The modifications of the technique described here do not preclude the customary collection of sections on tape (Ullberg 1979) This would permit a study of the functional anatomy not only on the macroscopic but also on the microscopic level As a particular anatomical detail can be traced and its location determined throughout the specimen a three dimensional image is obtained Cryosectioning rendered valuable and unequivocal information in this study and would certainly be applicable to similar investigations of other musculoskeletal organs As a frozen specimen can be radiographed and sectioned in identical planes it would lend itself particularly to comparative radiographic anatomical investigations

In the knife dissection study 54 of the 58 communicating bursae were *composite bursae* as they consisted of the bursa beneath the gastrocnemius tendon and the capsule and the bursa between the tendons of the gastrocnemius and semimembranosus muscle *This bursa is called the gastrocnemio semimembranosus bursa* although bursa subgastrocnemio gastrocnemio semimembranosa would be the proper denomination

Despite the high incidence of such communications and the fairly uniform shape of the opening this is not described in any detail or illustrated in the contemporary standard textbooks including those of Corning Lang & Wachsmuth Rauber Kopsch Cunningham Benninghoff Goerttler Grant Hafferl and Gray In the orthopaedic literature the communication is commonly depicted as a hole through which the synovial membrane protrudes (see Introduction)

In addition the present study demonstrated *a thin area in the capsule* in all specimens immediately distal to the line at which the postero medial capsule conjoined with or had separated from the gastrocnemius tendon Apart from this particular weak portion the capsule was thick No other preformed soft spots liable to yield to a synovial protrusion were seen even at the level of the posterior oblique ligament (Figures 12 and 14)

The deep portion of the bursa commonly referred to as the ' neck i e the sub gastrocnemial portion constantly forms a cavity of considerable extent in the medio lateral direction but narrow in the sagittal plane On lateral arthrograms only its nar row dimension is seen and for this reason it may have been misinterpreted as being a nar row stalk or pedicle

During knee extension the upper rim of the capsule is firmly compressed between the condyle and the overlying tendons Especial ly on the cryosections of knees that had been frozen during extension this mechanism in variably caused a hermetic *closure of the communication* The thin capsular rim ad mittedly resembles the cusp of a heart valve (Figures 8 and 9) but this does not imply a unidirectional valve mechanism in all com municating bursae (Taylor & Rana 1973) As the synovial fluid is emptied from the an *terior to the posterior* portions of the bursa (cyst) on extension of the knee this obvious ly distends its wall and this would explain why patients with popliteal cysts experience most discomfort when the knee is extended

The a a hment of the medial meniscus to the capsule is rather loose posteriorly whereas its central portion is intimately in terwoven with the capsular fibres a finding consistent with the observations of Oretorp (1978) The loose capsular connection of the posterior horn does not prevent the semi membranosus tendon from *exerting traction on the capsule* via its capsular arm This was also confirmed by the simulated pull on this tendon in the course of the present dissection study On the other hand the diagonal de formation of the communication observed on application of *torque* stress to the knee might have been due to traction forces from the meniscus acting on the postero medial portion of the capsule

Lindgren and Willen (1977) reported progressive rarefaction and degeneration of the fibroelastic tissue between the joint cavity and the gastrocnemio semimembra nosus bursa during ageing which eventually for example in combination with a sudden strain causes the communication to occur On the other hand the likewise constant bursa beneath the lateral head of the gastro cnemius muscle is reported to communicate with the joint far less frequently (Bardeleben & Haeckel 1901 Fick 1904 Testut & Jacob 1909 Hafferl 1969) This difference might be explained by continuous attrition due to capsular pull since at the medial side a heavy tendon (of the semimembranosus) inserts di rectly into the capsule and medially the semi lunar cartilage is intimately attached to the capsule whereas the lateral side lacks a cap sular tendon insertion and the lateral menis cus is mobile in relation to the capsule The increasing incidence of communication be tween the knee joint and the g s bursa with advancing age and the functional and mor phological finding of the present investiga tion would seem to suggest that this commu nication is a condition which is acquired during life

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In the clinical material of the present study a *valve mechanism* was demonstrated at the site of communication in 10 of the knees preoperatively by means of a specific arthrographic technique (Lindgren & Rauschning) In these cases contrast medium from the joint cavity readily passed over to the cyst, while no passage in the opposite direction occurred when the cyst was manually compressed As membranes and synovial folds were found at operation in these cases, it is conceivable that they constitute the pathoanatomical basis of the valve mechanism

Cryosectioning of undecalcified specimens frozen *in situ* and then removed as modified to suit the purpose of this study allowed an examination of the true and undistorted anatomy of the ice filled joint and bursa and the relation of the bursa to the capsule and tendons As no artifacts such as may result from conventional histological procedures occurred the sections reflected the true interrelationship of structures at each particular level *The filling of the synovial cavities with* coloured water was helpful in delineating the extensions of the bursa as the synovial membrane was tinted blue No difficulties were encountered in sectioning the bone not even the cortical bone in the metaphysis The image obtained from the rubbed surface of the block displayed natural colours making it easy to recognise and interpret the individual structures By observing the variations *of fluid filling of the different compartments* of the bursa in different positions of the knee the functional anatomy could be examined in a frozen state The modifications of the technique described here do not preclude the customary collection of sections on tape (Ullberg 1979) This would permit a study of the functional anatomy not only on the macroscopic but also on the microscopic level As a particular anatomical detail can be traced and its location determined throughout the specimen a three dimensional image is obtained Cryosectioning rendered valuable and unequivocal information in this study and would certainly be applicable to similar investigations of other musculoskeletal organs As a frozen specimen can be radiographed and sectioned in identical planes it would lend itself particularly to comparative radiographic anatomical investigations

In the knife dissection study 54 of the 58 communicating bursae were *composite bursae,* as they consisted of the bursa beneath the gastrocnemius tendon and the capsule and the bursa between the tendons of the gastrocnemius and semimembranosus muscle This bursa is called the gastrocnemio semimembranosus bursa although bursa subgastrocnemio gastrocnemio semimembranosa would be the proper denomination

Despite the high incidence of such communications and the fairly uniform shape of the opening this is not described in any detail or illustrated in the contemporary standard textbooks including those of Corning Lang & Wachsmuth, Rauber Kopsch Cunningham Benninghoff Goerttler Grant Hafferl and Gray *In the orthopaedic literature* the communication is commonly depicted as a hole through which the synovial membrane protrudes (see Introduction)

In addition the present study demonstrated *a thin area in the capsule* in all specimens immediately distal to the line at which the postero medial capsule conjoined with or had separated from the gastrocnemius tendon Apart from this particular weak portion the capsule was thick No other preformed soft spots liable to yield to a synovial protrusion were seen even at the level of the posterior oblique ligament (Figures 12 and 14)

SUMMARY

A survey of the literature on human popliteal cysts revealed a marked divergence of opinion regarding their origin Some recent publications indicate however that these cysts arise from the gastrocnemio semimembranosus bursa (g s bursa) Following routine excision of a popliteal cyst recurrences and postoperative complications are common even if a closure of its communication with the joint cavity has been attempted The present investigation was therefore undertaken to study the topographical and functional anatomy of the normal g s bursa in 120 post mortem specimens and to record the surgical morphology during the course of 26 operations on popliteal cysts

In the *anatomical investigations* both conventional knife dissections and serial cryo sectioning of large undecalcified specimens frozen in situ were performed The original technique (Ullberg 1954 1977) which mainly concerned whole body autoradiography of experimental animals was applied on human joints and modified to permit a detailed examination of the undistorted macroscopic anatomy of the structures in the vicinity of the bursa The optimum surgical approach to the capsular opening was sought with due regard to the popliteal sensory nerves In knees without a communication between the joint and the g s bursa fibre light transillumination invariably revealed a weak area in the joint capsule distal to its junction with the gastrocnemius tendon No other thin portions were disclosed When a communication was present it always appeared as a transverse slit separating this thin capsular portion from the overlying tendinous origin of the gastrocnemius Rotation of the lower leg and pull on the semimembranosus tendon simulating intravital conditions deformed and widened the capsular opening indicating that even during normal use of the joint tearing forces from the capsule might exert traction on the communication The increasing incidence of communication with advancing age and the morphological findings in the present studies would suggest that this condition is acquired during life

During operation all popliteal cysts were unequivocally identified as fluid-distended communicating g s bursae but in 50% the normal bursal communication with the joint was concealed by synovial membranes The deep portion of the cyst lacked a fibrous wall of its own and only consisted of the bursal lining of the tendons and capsule from which the cyst could not be dissected free

Based on these morphological results an improved surgical approach is proposed The necessity for radical excicion of all cyst tissue is questioned The thick gastrocnemius tendon lying over the communication lends itself to form a pedicle flap for closure of the opening and for reinforcement of the weak capsular portion

CONCLUSIONS

Some anatomical features established in the present studies would seem to be of special importance for the surgical technique in operations on popliteal cysts and should receive particular attention

1. All popliteal cysts in the present series were unequivocally identified as distended communicating gastrocnemio semimembranosus bursae
2. For surgical exposure a longitudinal incision following the semitendinosus tendon would provide good access to the capsular opening and involve little risk of damage to cutaneous nerves Flexion of the knee facilitates retraction of the tendons
3. The deep portion of a popliteal cyst is the natural (bursal) synovial lining of the joint capsule and the tendons It has a considerable extension in the mediolateral direction but is narrow ventrodorsally
4. This part of the cyst cannot be isolated by dissection unless a substantial amount of tendon and muscle tissue is taken along with it Not even if this is done will a pedicle (stalk, neck, narrow canal) form that can be ligated, divided and inverted
5. As the constancy and size of the bursa would seem to reflect its functional purpose of reducing friction between the capsule and the tendons it might be questioned whether at operation on popliteal cysts all synovial lining tissue should be radically excised as is commonly advocated axiomatically by many surgeons (see Introduction)
6. The communication between the cyst and the joint cavity invariably has the shape of a transverse slit and is located beneath the tendon of the medial head of the gastrocnemius muscle, roughly 3 cm distal to its origin
7. At operation all popliteal cysts were found to communicate with the joint cavity but in 50% extraarticular synovial membranes partially or totally concealed the bursal communication with the joint
8. The upper rim of the capsule is sharp and the adjacent portion of the capsule is thin, and on the gastrocnemius tendon no rim exists that would facilitate suturing Moreover after such closure the adjacent capsule would still be thin and liable to be torn or to yield A durable closure of the communication would also seem to demand a reinforcement of this particular area but for anatomical reasons free tendon grafts are not easily fitted into the opening
9. Capsular tearing forces obviously exert pull on the capsular opening and they must be taken into account at the surgical repair
10. As the gastrocnemius tendon is thick and as it always covers the capsular opening with sufficient overlapping, it lends itself to form a pedicle flap which is easily sutured to the capsule This repair appears appropriate both to eliminate the capsular tearing forces and to reinforce the thin portion of the capsule without appreciably weakening the tendon A series of operations on popliteal cysts using this capsuloplasty has given encouraging results

Fischedick O (1969) Veränderungen des hinteren Anteils der Kniegelenkskapsel im Arthrogramm *Chirurg* 40 408—411

Fischedick O (1971) Zur Pathologie des Band und Kapselapparates im Arthrogramm *Fortschr Röntgenstr* 115 312—320

Foucher F (1856) Memoire sur les kystes de la region poplitée *Arch gen Med* 8 313—335

Fullerton A (1916) The surgical anatomy of the synovial membrane of the knee joint *Brit J Surg* 4 191—200

Garnier M (1890) *Étude sur les kystes poplites* These de Paris

Gask and Wilson Vide Wiles P 1949

Goldschеider E (1898) Ein Beitrag zu den Hygromen des Knies *Brun s Beitr klin Chir* 22 169—190

Goldstein L A and Dickerson R C (1974) *Atlas of orthopaedic surgery* The Mosby Company St Louis

Grant B J (1962) *An atlas of anatomy* 5 ed Williams Baltimore

Gray s Anatomy Descriptive and applied Vide Johnston and Davis 1974

Gibbon G C (1885) Enlargement of the bursa beneath the semimembranosus muscle after injury suppuration extending to the knee joint aspiration amputation recovery remarks *Lancet* i 427—428

Gristina A G and Wilson P D (1964) Popliteal cysts in adults and children A review of 90 cases *Arch Surg* 88 357—363

Gruber W (1845) Uber die Ausstulpungen der Synovialkapsel des Kniegelenkes und uber die chirurgische Wichtigkeit der Communikation ders iben mit einigen benachbarten Kniе schleimbeuteln *Vierteljschr prakt Heilk* 5 95—105

Gruber W (1846) *Uber die durch Wassersucht bedingte krankhafte Erweiterung des zwischen dem Musculus gastrocnemius internus dem Musculus semimembranosus und der Kniegelenkskapsel gelagerten Schleimbeutels in chirurgisch anatomischer chirurgisch-diagnostischer und operativer Beziehung* G Wigand Leipzig 1—28

Gruber W (1856) Vorläufige Anzeige der Entdeckung des Processus supracondyloideus ossis femoris internus und der Bursa supracondyloidea genu des Menschen *Bull phys mathem de l Acad Imp des Sc de St Petersbourg* 14 267—270

Gruber W (1857) *Die Knieschleimbeutel (Bursae mucosae genuales)* F Ehrlich Prag

Gruber W (1865) Zu den hernienartigen Aussackungen der Bursae mucosae ausserhalb ihrer Lagerstätte I Hernienartige Aussackung der Bursa mucosa genualis supracondyloidea in die Fossa poplitea von enormer Grösse *Österreich Zschr f prakt Heilk* 11 607—611

Gruber W (1869) Hygrom der Bursa mucosa genualis retrocondyloidea interna semimembranoso-gastrocnemialis *Österreich Zschr prakt Heilk* 15 961—964

Gruber W (1885) Hygrom von enormer Grösse an der Bursa genu mucosa retrocondyloidea interna *Virchows Arch path Anat* 99 489—492

Hafferl A (1969) *Lehrbuch der topographischen Anatomie* neubearb von W Thiel 3 Auflage Springer Berlin Heidelberg New York

Haggart G E (1938) Posterior hernia of the knee joint A cause of internal derangement of the knee *J Bone Jt Surg* 20 363—373

Haggart G E (1943) Synovial cysts of the popliteal space Clinical significance and treatment *Ann Surg* 118 438—444

Hammer U (1920) Beiträge zur Kenntnis des Hygroms der Bursa semimembranosa *Bruns Beitr z klin Chir* 118 610—626

Harvey J P and Corcos J (1960) Large cysts in lower leg originating in the knee occurring in patients with rheumatoid arthritis *Arthr and Rheum* 3 218—228

Hawkes F (1899) Inflammation of the bursa gastrocnemio-semimembranosa With a report of four cases of enlargement and distention of this bursa treated by excision *Ann Surg* 30 61—78

Heineke W (1868) *Die Anatomie und Pathologie der Schleimbeutel und Sehnenscheiden* (Dissertation) A Deichert Erlangen

Hemet P (1900) *Contribution a l etude des kystes poplites* These La Faculte de Medicine Paris

Henle J (1871) *Handbuch der systematischen Anatomie des Menschen* Band I Knochenlehre *3 Auflage* F Vieweg Braunschweig

Hoffman B K (1963) Cystic lesions of the popliteal space *Surg Gynec Obstet* 116 551—558

Holmes T (1870) *A system of surgery theoretical and practical in treatises by various authors* 2nd ed Longmans Green and Co London

Hooper J C and Brookler M (1971) Popliteal cysts and their rupture in the rheumatoid arthritis simulating thrombophlebitis *Med J Aust* 1 1171—1173

Hort W and Mittelmeier (1975) Die Weichteilgeschwulste der Kniekehle *Z Orthop* 113 102—110

Hutton J A (1895) Bursa communicating with the knee joint excision *Brit med J* 1 412

Johnston and Davis (1974) *Gray s Anatomy Descriptive and applied* 35 ed Longmans New York

Justis J (1971) *Affections of fascia and bursae* In *Campbell s operative orthopaedics* 5th ed ed by Crenshaw A H The Mosby Company St Louis

REFERENCES

Ackerman L V (1959) *Surgical pathology* 2nd ed The C V Mosby Comp St Louis

Adams R (1840) Chronic rheumatic arthritis of the knee joint *Dublin J med Sci* 17 520—522

Adams R (1839—1847) Abnormal conditions of the knee joint *Cyclopedia anat physiol* (London) 3 48—78

Aegerter E and Kirkpatrick J A (1975) *Orthopaedic diseases physiology—pathology—radiology* 4th ed W B Saunders Co Philadelphia London Toronto

Albin B S (1734) Historia musculorum hominis Lugd Batav

Anson B J and Maddock W G (1952) *Callander s surgical anatomy* 3rd ed W B Saunders Co Philadelphia—London

Apley A G (1968) *A system of orthopaedics and fractures* 3rd ed Butterworths London

Baker W M (1877) The formation of synovial cysts in the leg in connection with disease of the knee joint *St Bart Hosp Rep* 13 245—261

Baker W M (1885) The formation of abnormal synovial cysts in connection with the joints (second communication) *St Bart Hosp Rep* 21, 177—190

Bardeleben K and Haeckel H (1901) *Atlas der topographischen Anatomie des Menschen* 2 Auflage G Fischer Jena

Baudouin (1855) *Des kystes synoviaux tendineux de la region poplitée* These de Paris

Beatty D C (1959) Rheumatoid cysts of the calf *Proc roy Soc Med* 52, 1106—1108

Benninghoff A and Goerttler K (1960) *Lehrbuch der Anatomie des Menschen* 7 Auflage Lehmann Munchen

Billroth T (1876) *Von dem chronischen Hydrops der Sehnenscheiden* In Die allgemeine chirurgische Pathologie und Therapie in funfzig Vorlesungen 8 Aufl G Reimer Berlin 600—601

Bond C J (1890) The treatment of enlarged bursae and ganglia by excision *Practitioner* 44 440—443

Borellini A Mammi G I and Ferrarini P (1971) Sindrome associata Cisti poplitea e lesione meniscale *Chir Organi Mov* 60 673—679

Bryan R S Di Michele J D and Ford G L (1967) Popliteal cysts Arthrography as an aid to diagnosis and treatment *Clin Orthop* 50 203—208

Brösicke (1899) *Lehrbuch der normalen Anatomie des menschlichen Körpers* Berlin

Buck R M McDonald J R and Ghormley R K (1943) Adventitious bursas *Arch Surg* 47 344—351

Burguet (1854) *Du diagnostic différentiel des tumeurs du creux poplite* Thèse de Paris

Burleson R J Bickel W H and Dahlin D C (1956) Popliteal cyst A clinico pathological survey *J Bone Jt Surg* 38 A 1265—1274

Childress H M (1954) Popliteal cysts associated with undiagnosed posterior lesions of the medial meniscus *J Bone Jt Surg* 36 A 1233—1240

Childress H M (1970) Popliteal cysts associated with undiagnosed posterior lesions of the medial meniscus *J Bone Jt Surg* 52 A 1487—1492

Ciolina (1904) *Ueber Hygrome der Kniekehle* Dissertation Erlangen

Clark W E (1949) *Practical anatomy revised and rewritten* E Arnold London

Colombo O (1965) Die Arthrozele der Kniekehle *Chir Praxis* 9, 583—588

Corning H K (1907) *Lehrbuch der topographischen Anatomie fur Studierende und Ärzte* J F Bergmann Wiesbaden

Crasselt C (1968) Arthrocelen bei rheumatischen Kniegelenkserkrankungen *Z Orthop* 104 570—579

Cravener E K (1932) Hernia of the knee joint (Baker s cyst) *J Bone Jt Surg* 14 186—187

Cruveilhier Vide Adams R 1839—47

Cunningham D J (1951) *Cunninghams textbook of anatomy* Williams & Wood Co New York

Davis G G (1918) *Applied anatomy The construction of the human body* 5th ed Lippincott Co Philadelphia

Dinham J M (1975) Popliteal cysts in children The case against surgery *J Bone Jt Surg* 57 B 69—71

Doppman J L (1965) Baker s cyst and the normal gastrocnemiosemimembranosus bursa Amer J Roentgenol 94 646—652

Dupuytren G (1829) Hydrarthrose enorme du genou — Antiphlogistiques — Purgatifs répétes — Guerison *La Clinique Hum de Med Univ (Paris)* 1 No 42 251

Edmunds L H and Hebble J G (1939) Posterior herniation of the knee joint *Seattle Virginia Mason Hosp Clin* 18 8—11

Etienne J C Menanteau B Gérard Y and Gougeon J (1976) Les kystes synoviaux du creux poplité étude radio clinique et pathogenique d une serie de 122 observations (13 genoux) *Un med Can* 105 544—558

Ficat P (1957) *Pathologie synoviale* In L arthro graphie opaque du genou Masson et Cie Paris

Fick R (1904) *Handbuch der Anatomie und Mechanik der Gelenke unter Berucksichtigung der bewegenden Muskeln* G Fischer Jena

Rauber Kopsch (1955) *Lehrbuch und Atlas der Anatomie des Menschen* Band 1 19 Auflage G Thieme Stuttgart

Rauschning W (1979) Serial cryosectioning of human knee joint specimens for a study of functional anatomy *Science Tools* 26 47—50

Rauschning W and Lindgren P G (1979) Popliteal cysts (Baker s cysts) in adults I Clinical and roentgenological results of operative excision *Acta orthop scand* 50 583—591

Rauschning W Popliteal cysts (Baker s cysts) in adults II Capsuloplasty with and without a pedicle graft *Acta orthop scand* 51 (in press)

Reinhardt K (1972) Popliteazysten und popliteogene Unterschenkelzysten (Bakerzysten) *Radiologe* 12 77—86

Rosenmuller J C (1799) *Alexander Monros Abbildungen und Beschreibungen der Schleimsäcke des menschlichen Körpers (Edinburg 1788)* ubersetzt umgearbeitet und vermehrt herausgegeben Breitkopf und Haertel Leipzig

Sachs A E and Rubinstein L (1946) Bilateral popliteal hernia Case report *Surgery* 20 385—387

Saegesser M (1956) *Spezielle chirurgische Therapie* 4 Auflage H Huber Bern und Stuttgart

Sheild A M (1898) Treatment by excision of bursal cysts in connection with the knee joint *Clin J* 11 371—375

Smillie I S (1974) *Affections of the synovial membrane* In *Diseases of the knee joint* Churchill Livingstone Edinburgh and London

Solomon L and Berman L (1972) Synovial rupture of the knee joint *J Bone Jt Surg* 54-B 460—467

Sonntag E (1916—17) Hygrom und Corpora libera der Bursa semimembranosa (Beitrag zur Pathogenese und Klinik der Schleimbeuteler krankungen *Langenbecks Arch klin Chir* 107—108 245—280

Synnestvedt A S D (1869) En anatomisk beskrivelse af de paa over og underextremiteter ne forekommende bursae mucosae støttet paa egne iakttagelser og ledsaget af tegninger efter udførte praeparater Thesis Christiania

Taylor A R and Rana N A (1973) A valve An explanation of the formation of popliteal cysts *Ann rheum Dis* 32 419—421

Testut L and Jacob O (1909) *Traité d anatomie topographique avec applications medico-chirurgicales* 2 eme édition Octave Doin et fils Paris

Tillaux P (1892) *Traité d anatomie topographique avec applications à la chirurgie* Asselin et Houzeau Paris

Touloukian R J (1971) Popliteal cysts in childhood *Surgery* 69 629—632

Ullberg S (1954) Studies on the distribution and fate of S^{35} labelled benzylpenicillin in the body *Acta radiol (Stockh) Suppl* 118 1—110

Ullberg S (1977) The technique of whole body autoradiography Cryosectioning of large specimens *Science Tools* Special issue 2—29

Ullberg S (1979) Personal communication

Vahvanen V (1973) Popliteal cyst A follow up study on 42 operatively treated patients *Acta orthop scand* 44 303—310

Wieser C Steiger U and Zinn W (1967) Zystische Pseudotumoren der Kniekehle im Kniearthrogramm *Radiol clin* 36 333—336

Wiles P (1949) *Essentials of orthopaedics* J & A Churchill London

Wilson P D Eyre Brook A L and Francis J D (1938) A clinical and anatomical study of the semimembranosus bursa in relation to popliteal cyst *J Bone Jt Surg* 20 963—984

Wolfe R D and Coloff B (1972) Popliteal cysts An arthrographic study and review of the literature *J Bone Jt Surg* 54-A 1057—1063

Kessler I and Silberman Z (1960) The development of popliteal cysts an arthrographic study *Clin Orthop* 18 149—156

Kirmisson E F (1892) *Maladies des membres* In Duplay, S and Reclus P *Traite de chirurgie* Tome 8 G Masson, Paris

Kirpila, J and Ripatti N (1958) On Baker s cyst and its treatment *Acta rheum scand* 4 296—302

Kuhn H H and Hemphill J E (1944) Baker s cyst Posterior herniation of the knee joint *Radiology* 42, 237—240

Lang J and Wachsmuth W (1972) *Praktische Anatomie Ein Lehr und Hilfsbuch der anatomischen Grundlagen arztlichen Handelns Bein und Statik* 2 Auflage Springer Berlin Heidelberg New York

Lapayowker M S Cliff M M and Tourtellotte C D (1970) Arthrography in the diagnosis of calf pain *Radiology* 95 319—323

Lewin P (1952) *The knee joint and related structures Injuries deformities diseases disabilities* Lea and Febiger Philadelphia

Lindgren P G and Willen R (1977) Gastrocnemio semimembranosus bursa and its relation to the knee joint I Anatomy and histology *Acta radiol (Stockh)* 18, 497—512

Lindgren P G (1977) — II Post mortem radiography *Acta radiol (Stockh)* 18 698—707

Lindgren P G (1978) — III Pressure measurements in joint and bursa *Acta radiol (Stockh)* 19 377—388

Lindgren P G (1978) — IV Clinical considerations *Acta radiol (Stockh)* 19, 609—622

Lindgren P G (1979) *Personal communication*

Lindgren P G and Rauschning W Clinical and arthrographic studies on the valve mechanism in communicating popliteal cysts *Arch Orthop Traumat Surg* (in press)

Longy (1852) *Essai sur le diagnostic des tumeurs du creux poplite* These de Paris

Malgaigne J F (1853) Observation des kystes sereux du jarret *Revue medico chirurgicale* 14 343

Malloch J D (1970) Popliteal cysts in children *Brit J Surg* 57 616—618

Mathias K (1977) Klinische und arthrographische Aspekte der Poplitealcysten *Chirurg* 48 384—389

Maudsley R H and Arden G P (1961) Rheumatoid cysts of the calf and their relation to Baker s cysts of the knee *J Bone Jt Surg* 43 B 87—89

Meire H B Lindsay D J Swinson D R and Hamilton E B D (1974) Comparison of ultrasound and positive contrast arthrography in the diagnosis of popliteal and calf swellings *Ann rheum Dis* 33 221—224

Merkel (1907) Handbuch der topographischen Anatomie Braunschweig Vide Hammer U 1920

Meyerding H W and van Demark R E (1943) Posterior hernia of the knee (Baker s cyst popliteal cyst semimembranosus bursitis medial gastrocnemius bursitis and popliteal bursitis) *J Amer med Ass* 122 858—861

Monro A secundus (1788) *A description of all the bursae mucosae of the human body* Elliot Edinburgh

Morscher E (1957) Semimembranaceuscysten Vorkommen und Besonderheiten im Kindersalter *Helv chir Acta* 3 266—294

Moser H (1950) Traumatische kommunizieren de Arthrozele in der Kniekehle *Zbl Chir* 75 942—950

Myles A B (1971) Posterior synovial leaks in arthritis of the knee *Proc roy Soc Med* 64 262—264

Nelaton (1851) *Leçon clinique sur les tumeurs de la region poplitee* (Paris) Vide Hemet P 1900

Ollivier (1855) *Du diagnostic differentiel des tumeurs du creux poplite* These de Paris

Oretorp N (1978) On the diagnosis and treatment of meniscus and ligament injuries in the knee especially on the medial side *Linköpings University Medical Dissertations No* 63

Orr T G (1951) *Operations of general surgery* 2nd ed W B Saunders Comp Philadelphia and London

Pallardy G Fabre P Ledoux Lebard G Renoux J P and Delbarre F (1971) Diagnostic des bursites et kystes poplites par arthrographie du genou *Rev Rhum* 38 345—360

Perri J A Rodnan G P and Mankin H J (1968) Giant synovial cysts of the calf in patients with rheumatoid arthritis *J Bone Jt Surg* 50 A 709—719

Piersol G A (1919) *Human anatomy including structure and development and practical considerations* 7th ed J B Lippincott Co Philadelphia London

Pinder I M (1973) Treatment of the popliteal cyst in the rheumatoid knee *J Bone Jt Surg* 55 B 119—125

Pitha Vide Gruber W (1845)

Poirier P (1886) Bourses sereuses du genou (region posterieure) Bourses sereuses de la region poplitee *Arch gén Med* 539—575

Power D (1885) An account of four cases of intermuscular synovial cysts *Trans path Soc Lond* 36 337—342

Power D (1887) Further specimens of intermuscular synovial cysts *Trans path Soc Lond* 38 381—386

Pulich J J (1975) Asymptomatic popliteal cysts *J Amer Osteopath Ass* 75 319—323

Rauber Kopsch (1955) *Lehrbuch und Atlas der Anatomie des Menschen* Band I 19 Auflage G Thieme Stuttgart
Rauschning W (1979) Serial cryosectioning of human knee joint specimens for a study of functional anatomy *Science Tools* 26 47—50
Rauschning W and Lindgren P G (1979) Popliteal cysts (Baker s cysts) in adults I Clinical and roentgenological results of operative excision *Acta orthop scand* 50 583—591
Rauschning W Popliteal cysts (Baker s cysts) in adults II Cap uloplasty with and without a pedicle graft *Acta orthop scand* 51 (in press)
Reinhardt K (1972) Popliteazysten und popliteogene Unterschenkelzysten (Bakerzysten) *Radiologe* 12 77—86
Rosenmuller J C (1799) *Alexander Monros Abbildungen und Beschreibungen der Schleimsäcke des menschlichen Körpers (Edinburg 1788)* ubersetzt umgearbeitet und vermehrt herausgegeben Breitkopf und Haertel Leipzig
Sachs A E and Rubinstein L (1946) Bilateral popliteal hernia Case report *Surgery* 20 385—387
Saegesser M (1956) *Spezielle chirurgische Therapie* 4 Auflage H Huber Bern und Stuttgart
Sheild A M (1898) Treatment by excision of bursal cysts in connection with the knee joint *Clin J* 11 371—375
Smillie I S (1974) *Affections of the synovial membrane* In *Diseases of the knee joint* Churchill Livingstone Edinburgh and London
Solomon L and Berman L (1972) Synovial rupture of the knee joint *J Bone Jt Surg* 54 B 460—467
Sonntag E (1916—17) Hygrom und Corpora libera der Bursa semimembranosa (Beitrag zur Pathogenese und Klinik der Schleimbeutelerkrankungen *Langenbecks Arch klin Chir* 107—108 245—280
Synnestvedt A S D (1869) En anatomisk beskrivelse af de paa over og underextremiteter ne forekommende bursae mucosae støttet paa egne iakttagelser og ledsaget af tegninger efter udførte praeparater Thesis Christiania
Taylor A R and Rana N A (1973) A valve An explanation of the formation of popliteal cysts *Ann rheum Dis* 32 419—421
Testut L and Jacob O (1909) *Traité d anatomie topographique avec applications medico-chirurgicales* 2 eme edition Octave Doin et fils Paris
Tillaux P (1892) *Traité d anatomie topographique avec applications a la chirurgie* Asselin et Houzeau Paris
Touloukian R J (1971) Popliteal cysts in childhood *Surgery* 69 629—632
Ullberg S (1954) Studies on the distribution and fate of S^{35} labelled benzylpenicillin in the body *Acta radiol (Stockh) Suppl* 118 1—110
Ullberg S (1977) The technique of whole body autoradiography Cryosectioning of large specimens *Science Tools* Special issue 2—29
Ullberg S (1979) Personal communication
Vahvanen V (1973) Popliteal cyst A follow up study on 42 operatively treated patients *Acta orthop scand* 44 303—310
Wieser C Steiger U and Zinn W (1967) Zystische Pseudotumoren der Kniekehle im Kniearthrogramm *Radiol clin* 36 333—336
Wiles P (1949) *Essentials of orthopaedics* J & A Churchill London
Wilson P D Eyre Brook A L and Francis J D (1938) A clinical and anatomical study of the semimembranosus bursa in relation to popliteal cyst *J Bone Jt Surg* 20 963—984
Wolfe R D and Coloff B (1972) Popliteal cysts An arthrographic study and review of the literature *J Bone Jt Surg* 54-A 1057—1063

ROLF ÖNNERFÄLT

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Fracture of the Tibial Shaft Treated by Primary Operation and Early Weight-Bearing

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John Charnley 1961

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Henning Höjer, Jan Gillquist and Sten-Otto Liljedahl, 1977

1 INTRODUCTION

The treatment of fractures of the shaft of the tibia has remained a subject of vigorous debate for several decades Hardly any other important fracture has inspired such a broad spectrum of opinion as regards optimal treatment the extreme belief in open surgery and rigid fixation promoted by the AO-group has fueled a reaction from Dehne et al (1961) Sarmiento (1967, 1970 1974) and their followers who have demonstrated that closed treatment only can prevent serious complications Between these extremes a more eclectic approach has emerged Bauer et al (1962) have shown that the incidence of deep infection and poor results are directly correlated to the cause of the fracture They proposed that the extent of soft tissue rather than bone injury should guide the choice of treatment open surgery and internal fixation would be well tolerated in low energy fractures but quite hazardous in high energy fractures This hypothesis was confirmed by Edwards (1965) in a controlled prospective series of 161 displaced fractures with but one case of deep infection

The fact that deep infection in fractures of the tibia can be virtually avoided does not mean that treatment routines cannot be improved and simplified Edwards usually kept his fractures in a full leg-length plaster without weight-bearing until the fracture healed in open transverse fractures this treatment could last a year or more By contrast Dehne et al (1961) Brown and Urban (1969) and Sarmiento (1967 1970 1974) have shown that the tibial fracture tolerates early weight-bearing but they seem to have accepted rather serious shortening and malalignment

The basis for the present investigation was to combine the principles of Edwards and Sarmiento The fractures were thus subjected to active primary treatment with open surgery and internal fixation in displaced longitudinal fractures and closed intramedullary nailing of displaced transverse fractures and they were then allowed early weight-bearing with free knee motion in a below-the-knee cast Already from the start the investigation was planned to permit a close comparison not only with Edwards s series but also with Olerud and Karlström s (1972a) review of tibial fractures treated by the AO compression plate In order to simplify this comparison the definitions and terminology used by Edwards (1965) and/or Olerud and Karlström (1972a) have been used

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After exclusion of the above patients the base material of the investigation comprised 105 patients Two of these had bilateral fractures and three sustained re-fracture after the initial fracture had healed In all three the re-fracture was caused by adequate trauma in two of these the fracture occurred distant to the initial fracture Therefore these three re-fractures were regarded as fresh fractures The base material thus comprised 110 fractures of the tibia (Figure 1)

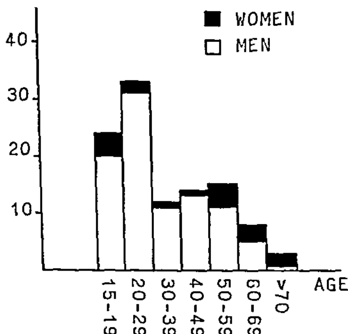


Fig 1

Age and sex distribution

Classification of the fractures (Table II)

The fractures were classified according to Edwards (1965) with but minor modifications

(1) Longitudinal vs transverse fractures Longitudinal fractures were defined as such fractures in which the fracture line formed an angle of less than 45° with the long axis of the diaphysis All other fractures were classified as transverse An additional classification was introduced by distinction between simple transverse fractures with an angle close to 90° and short oblique fractures with an angle less than 90°

II MATERIAL

This prospective investigation was started August 1, 1973 and ended June 30, 1976 The source material comprised all patients 15 years and older with a fracture of the tibia between the tibial tuberosity and 3 cm proximal to the ankle joint in whom primary treatment was started at the Department of Orthopaedics in Lund during the period of investigation and who did not receive secondary treatment elsewhere The following groups were excluded from the source material

(1) 17 patients who received primary treatment elsewhere,
(2) 11 patients who received secondary treatment elsewhere,
(3) 10 patients with 11 fractures who had other injury or disease which prevented early mobilisation with weight-bearing (Table 1)
(4) 3 patients who were never subjected to early weight-bearing because the surgeons in charge had misunderstood the agreed treatment schedule
(5) 3 patients with 4 fractures in which local skin- or other soft tissue problems were thought to prevent the treatment schedule One of these patients had such extreme obesity that the PTB-plaster was judged not to give sufficient stability to her rather proximal fracture One patient was an 87-year old man with such fragile skin that it was deemed unwise to apply a non-padded plaster early One patient with bilateral tibial fractures had a crush injury of the left popliteal artery and very slow healing of the soft tissues

Table 1
Fractures not subjected to early weight-bearing

Multiple injury or disease		11
Skull injury	2	
Thoracic and abdominal injury	1	
Pelvic and/or femoral fracture	6	
Senility	2	
By mistake		3
Soft tissue problems		4
Total		18

In none of the 13 patients in groups 3 and 4 above did the fracture itself prevent early weight-bearing

Table III

Further classification of displaced transverse fractures of the tibial shaft

	Closed	Open	Total
Simple transverse fractures	13	5	18
Short oblique fractures	11	8	19
Comminuted fractures	8	10	18
Severely comminuted fractures	1	1	2
Double fractures	4	3	7
Total	37	27	64

Table IV

The size of the wound associated with the tibial fractures

	≤1 cm	2-5 cm	6-10 cm	>10 cm	Total
Longitudinal fractures	5				5
Simple transverse fractures	1	4			5
Short oblique fractures	5	1	1	1	8
Comminuted fractures	1	8		1	10
Severely comminuted fractures	1				1
Double fractures	2	1			3
Total	15	14	1	2	32

Table V

Fracture level

Proximal metaphysis	1
Diaphysis	96
Distal metaphysis	13
Total	110

(2) Displaced fractures Fractures with minimal displacement were classified as non-displaced Contrary to Edwards (1965) no attempt was made to sub-classify the displaced fractures, before X-ray examination all grossly displaced fractures were reduced and in six fractures traction was applied to the calcaneus In the displaced fractures the fibula was not fractured in two longitudinal fractures, six closed transverse fractures and six open transverse fractures

(3) Comminution (Table III) Fractures with an intermediary fragment larger than half the diameter of the diaphysis were classified as comminuted Comminuted fractures with additional intermediary fragments were classified as grossly comminuted When the diaphysis had fractured at two separate levels the fracture was classified as a double fracture

(4) Closed vs open fractures The size of the wound is shown in Table IV In all the open longitudinal fractures the wounds were obviously caused by simple piercing of the skin from within

(5) Fracture level (Table V) Edwards (1965) had recognized three fracture levels, proximal midshaft and distal As it now seems well established that the healing conditions of truly diaphyseal fractures is the same regardless of level (Ellis 1958b, Nicoll 1964, Edwards 1965 Hoaglund and States 1967) it seemed more relevant to distinguish between diaphyseal and metaphyseal fractures

Table II

Classification of tibial shaft fractures (Edwards 1965)

		Present series		Uppsala series		Malmö series	
		Number	%	Number	%	Number	%
1	Displaced longitudinal closed	24	22	44	33	47	26
2	Displaced longitudinal open	5	4	6	4	5	3
3	Non-displaced longitudinal open	-	-	-	-	-	-
4	Displaced transverse closed	37	34	46	34	62	34
5	Displaced transverse open	27	24	38	28	47	26
6	Non-displaced transverse open	-	-	-	-	-	-
7	Non-displaced transverse closed	16	15	1	1	11	6
8	Non-displaced longitudinal closed	1	1	-	-	9	5
	Total	110	100	135	100	181	100

The Uppsala series refers to Olerud and Karlström 1972a

The Malmö series refers to Edwards s prospective series (1965)

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Fracture level

Proximal metaphysis	1
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Total	110

Cause of the fractures (Table VI)

Traffic injury accounted for 40 % of the fractures, half of those occurred in patients riding mopeds or motor cycles All sport fractures were soccer injuries, the lack of ski injuries is explained by the almost total absence of snow in southern Sweden during the investigation period As regards the fractures caused by a fall, a height of 3 metre distinguished between low and high energy fractures

Associated injury (Table VII)

Eleven fractures occurred in patients with multiple injuries Nine of these were victims of traffic accidents, one fell from a height of 4 metres and one was involved in the collapse of a building scaffold

Table VI

Cause of tibial fracture

	No
Severe violence	
Pedestrian	13
Moped- or motorcyclist	21
Cyclist in collision with a car	2
Car driver or passenger	8
Fall from a height of more than 3 metres	3
Blow from a heavy object or a crush injury	8
Total	55
Moderate violence	
Soccer injury	29
Single bicycle accident	1
Fall at ground level or from a low height	25
Total	55

Table VII

Associated injuries

Injury	Number
Head injury	3
Vertebral fracture	1
Pelvic fracture	2
Femoral fracture	1
Clavicular fracture	1
Scapular fracture	4
Humeral fracture	2
Radial fracture	1
Foot fracture	2
Spleen rupture	1
Brachial plexus injury	1
Total	19

These 19 injuries occurred in 11 patients

The aim of this investigation was (1) to provide primary definitive treatment as soon as possible, (2) to institute early weight-bearing in a PTB-plaster and (3) to do a follow-up not less than 6 months after the fracture

Primary treatment (Table IX)

All treatment before the application of the PTB-plaster was defined as primary treatment Operations were planned to be performed as early as possible, this meant that the operations were carried out by the surgeon on duty and therefore the number of surgeons involved at this stage was quite large, some 15 In 60 fractures the operation was performed within 24 hours, usually less than 12 hours, and in 10 fractures the operation was delayed 24 hours or more (Table VIII) The reason for this delay was concomitant injury or disease in six fractures (two head injuries, one ruptured spleen, one vertebral fracture, one intoxication, one poor skin), unacceptable initial reduction in two fractures, delays in transportation from site of injury to the hospital in one fracture, and unknown reasons in one fracture

Table VIII

Hours between injury and definitive operative treatment

	1-6	7-12	13-24	24
Longitudinal fractures	5	8	8	3
Transverse closed fractures	7	13	1	5
Transverse open fractures	9	6	3	2
Total	21	27	12	10

In accordance with Edwards (1965) the cause of the fractures and thus the extent of skin damage decided the choice of primary treatment A distinction was therefore made between longitudinal and transverse fractures

(1) Longitudinal fractures Open reduction and osteosynthesis was carried out whenever displacement was deemed more than acceptable One usually two or occasionally more screws were chosen rather than encircling wires which provide less stability (Lindahl 1964) and may cause osteonecrosis (Norberg 1977) In 18 of 29 displaced fractures osteosynthesis with screw(s) was thus performed In one fracture an encircling wire was used because the fixation with screws did not succeed In five fractures closed reduction and

Table IX

Primary treatment in tibial fractures

Type of fracture	Plaster only	Closed reduction	Rush pin	Screw(s)	Encircling wire	Transfixation	Total
Displaced longitudinal closed	3	2	4	14	1		24
Displaced longitudinal open			1	4			5
Displaced transverse closed	4	6	25			2	37
Displaced transverse open	4	4	18	1			27
Non-displaced transverse closed	16						16
Non-displaced longitudinal closed	1						1
Total	28	12	48	19	1	2	110

Plaster was used in all cases and all fractures subjected to osteosynthesis or transfixation were reduced

osteosynthesis with a Rush-pin was preferred because of either marked swelling or osteopenia In the remaining five fractures an acceptable position was obtained without need for an open operation In the five open fractures the wound was closed with primary suture after excision of the wound margins

(2) Transverse fractures Non-displaced fractures were treated with a long-leg cast only Displaced fractures which could be stably reduced by closed methods, likewise had a long-leg cast only If stable reduction could not be obtained, blind nailing with a Rush-pin was performed In comminuted fractures where the Rush-pin did not give sufficient stability, transfixation in plaster was preferred The Rush-pin was introduced from behind the tibial tuberosity after length-wise splitting of the patellar ligament, so as to cause as little irritation as possible from the unpadded PTB-cast The Rush-pin was chosen because it had been used successfully by Edwards (1965) and had been used for a long time in this department Three-point fixation (Rush 1955) was not aimed at, the only purpose of the pin was to prevent shortening of the fracture by sliding of the fragments In all 27 open transverse fractures the wounds were sutured primarily with a relaxing incision in only one fracture In 18 fractures the displacement was reduced to a stable position without use of osteosynthesis In 43 fractures fixation was obtained with a Rush-pin One open, short oblique fracture in the distal metaphysis was stabilized with a screw Transfixation was used in two comminuted fractures

(3) Antibiotic treatment All open fractures received antibiotics immediately on admission (Bowers et al 1973, Patzakis et al, 1974, Gustilo and Anderson 1976, Lidgren and Sandegard 1977) As a principle fractures with small wounds were treated with penicillin and fractures with large wounds with a combination of penicillin and ampicillin In cases where there was judged to be a risk of infection with Staphylococcus aureus resistent to penicillin, the latter was substituted by cloxacillin In order to simplify this schedule all open fractures were treated with cephalothin/cephalexin during the last six months of the investigation

(4) Primary plaster fixation All fractures were initially stabilized with a long-leg plaster and the patients were mobilized with crutches without weight-bearing as soon as possible, usually within the first couple of days

(5) Additional primary treatment (Table X) 19 fractures required a total of eight cast removals for re-reduction under anaesthesia and 14 wedgings In one of the re-reductions the Rush-pin was partly extracted and re-inserted in a better position All wedgings were made on the long-leg cast If the fracture angulated after the long-leg

cast had been changed to a PTB-ca t a new PTB-cast was applied as recommended by Sarmiento (1974) no attempts were made to wedge the PTB-cast

In one fracture a fasciotomy was performed because of threatening compartment syndrome after a few days a split skin graft was applied

Table X
Additional primary treatment

Pe-reduction	8
Wedging	14
Fascictomy	1
Secondary skin clorure	1
Total	24

Early weight-bearing

After 2-3 weeks the long-leg plaster was removed and a PTB-cast (Sarmiento 1967) was applied if wound healing and swelling permitted (Table XII) The patients were encouraged to bear full weight in the PTB-cast as soon as it was dry and most of the patients could do this without discomfort The patients returned for X-ray control three weeks later and if they were still comfortable the original PTB-cast was retained for another six weeks At twelve weeks the plaster was removed and the fracture was examined clinically for stability and by X-ray for evidence of callus formation The decision as to whether further plaster fixation could be dispensed with was based on these examinations and on the nature of the fracture In the majority no further plaster was deemed necessary and in a few cases the plaster was removed before 12 weeks, for example in non-displaced fractures and in some where already the six-week Y-ray examination showed evidence of callus formation The general schedule shown here was followed in 80% of the fractures in as much as they required only two PTB-casts (Table XI)

Table XI
Number of PTB-casts

Type of fracture	1	2	3	3	Total
Displaced longitudinal	17	8	4		29
Displaced transverse closed	13	16	3	5	37
Displaced transverse open	10	9	5	3	27
Non-displaced	15	2			17
Total	55	35	12	8	110

Table XII

Days between injury and first PTB-cast

Type of fracture	1-7	8-14	15-21	22-28	29-35	36-42	43-49	50-56	m $\pm$ s e m	median
Displaced longitudinal		2	6	12	5		2	2	27 $\pm$ 2	23
Displaced transverse closed		3	11	12	4	4	2	1	26 $\pm$ 2	25
Displaced transverse open			7	12	4	2	1	1	27 $\pm$ 2	25
Non-displaced	2	6	6	3					15 $\pm$ 2	17
Total	2	11	30	39	13	6	5	4		

Secondary treatment (Table XIII)

Because of delayed healing six fractures were treated with fibulotomy, reaming of the medullary cavity and Kuntscher-nailing (Christensen 1973) and three fractures were treated with subcortical cancellous bone-grafting (Phemister 1947 Charnley 1961) One of the graft procedures was performed after it had been found that a planned Kuntscher-nailing could not be carried through The Kuntscher-nailed fractures were allowed full weight-bearing without plaster immediately after the operation The graft operated fractures were stabilized in a PTB-cast with full weight-bearing for three months in two cases and 6 5 months in one case

Table XIII

Secondary treatment for delayed union

Kuntscher-nailing	6
Bone grafts	3
Total	9

In planning the treatment of the series of fractures described here it was decided that any secondary operation should be performed as early as possible in order to avoid unnecessary delays However no definite time limit was set for these interventions Some of these secondary operations were performed rather late (Table XIV) because some fractures believed to be stable, later developed pain on weight-bearing the indication for the secondary operation was pain in the fracture region and/or radiographic evidence of threatening pseudarthrosis

Table XIV

Weeks between initial injury and secondary treatment for delayed union

Type of fracture	20-29	30-39	40-49	50-59	Total
Transverse displaced closed	2	1	1	1	5
Transverse displaced open	1	1	1	1	4
Total	3	2	2	2	9

Healing times

Healing was judged to have occurred when the fracture was clinically stable and did not elicit pain on palpation or manual stress the final plaster was thus often removed before radiographic evidence of complete healing was observed However osteosynthesis with screws in longitudinal fractures often is quite stable and hence it was

difficult to evaluate the degree of healing in such cases clinically and by X-ray because visible callus formation was minimal In these fractures, therefore, plaster fixation was usually carried through the full twelve weeks The healing times were analyzed with graphic probit analysis (Edwards and Nilsson 1965) The healing time for fractures subjected to secondary Kuntscher-nailing could not be determined because these fractures were stabilized at operation These fractures were not included in the analysis of healing times

Delayed union was defined as healing time longer than 20 weeks (Nicoll 1964)

Removal of osteosynthesis material

As the patients recovered from the fracture episode, the proximal end of the Rush-pin usually caused some pain during activities like running, crouching and kneeling In most cases the pin was therefore removed after about one year, it was left in eight patients who were relatively old and inactive and did not experience any discomfort *The screws were removed in only two cases and then because of aching pain in the* fracture region

Follow-up

The patients were re-examined between 6 months and 3 1/2 years after the initial injury In the base material 106 out of the 110 fractures were re-examined i e 96 % Two patients with non-displaced transverse fractures had moved far away from this region, one patient with a comminuted transverse fracture which had healed without complications refused to appear for re-examination and one patient with a displaced longitudinal fracture had died from reasons unrelated to the fracture episode

The 18 fractures which for various reasons had been excluded from the source material (Groups 3-5, page 8) were subjected to re-examination However, one of these patients, a mentally retarded man, was not examined because he had been moved to a remote long-term care unit

The parameters examined at the re-examination (Table XV) were chosen from Edwards (1965) and Olerud and Karlström (1972a) to permit comparison with their series In the final classification of the results observed at re-examination sports activities were disregarded most patients had never participated in sport activities Furthermore shortening, angulation or malrotation were disregarded unless they were symptomatic in terms of the other [illegible] amined In agreement with Olerud and Karlström (1972a) those fractur[illegible] as excellent with symptoms only in Group I,

good those with one or more symptoms in Group II acceptable those with one symptom in Group III but without any untoward subjective problems, and poor those with symptom(s) in Group III with poor function

Re-examination of the radiographic material

The radiographic material was re-examined with regard to malalignment Displaced fractures were re-examined to ascertain whether the osteosynthesis had diminished the initial shortening As regards angulation the true angle was determined according to Norman (1965) see Fig 2 For those fractures where the final angulation was more than 5^{o} the X-ray material before and after weight-bearing in the PTB-cast was examined to evaluate whether the angulation was due to early weight-bearing

Statistical methods

For calculation of statistical significance the Z-test, chi-square test, Fischer s exact test Student s t-test and F-test were used

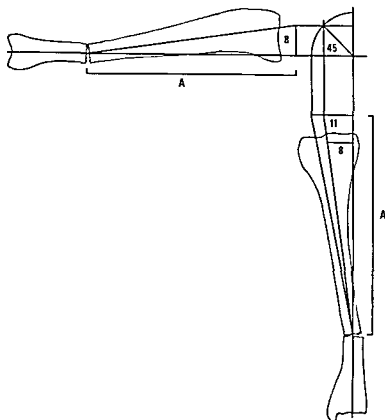


Fig 2 Determination of the true fracture angle according to Norman (1965)
A fracture with 8^{o} of angulation in the frontal and lateral projections The true angle is 11^{o} directed 45^{o} anteriomedially

Table XV

Definition of parameters at the follow-up examination

	I	II	III
Subjective symptoms			
1 Work capacity	Unchanged	Difficulty in doing heavy work	Seated work only
2 Sports activity	Unchanged	Finished with some sport because of injury	Finished with all sports because of injury
3 Difficulty in walking	None	Slight limp after severe exercise	Constant limp
4 Pain at fracture area	None or neglibile	Moderate symptoms	Severe symptoms pain at rest
5 Ankle joint symptoms	None or neglibile	Moderate symptoms	Severe symptoms
6 Knee joint symptoms	None or neglibile	Moderate symptoms	Severe symptoms
Objective signs			
7 Knee motion	Normal	0-110°	Lack of full extension, flexion to less than 90°
8 Ankle motion	Less than 10° loss of dorsiflexion, less than 20° loss of plantar flexion	Dorsiflexion over 90°, less than 30° loss of plantar flexion	Dorsiflexion less than 90° more than 30° loss of plantar flexion
9 Foot motion	Less than 25% decrease of pro- and supination	Moderately decreased	Severely decreased
10 Foot contracture	None	Moderate	Severe cavus deformity
11 *Calf atrophy*	Less than 1 cm	1-2 cm	More than 2 cm
12 *Malleolar swelling*	Less than 1 cm	1-2 cm	More than 2 cm
13 Shortening	Less than 1 cm	1-2 cm	More than 2 cm
14 Angulation deformity	5° or less	6-10°	More than 10°
15 Rotational deformity	10° or less	11-20°	More than 20°

IV RESULTS

Complications (Table XVI)

(1) Wound infection was defined as a wound with clinical evidence of infection thus disregarding the results of bacterial culture Deep infection was not observed in this series In six fractures a superficial wound infection was observed none of these required more than antibiotics In two of these the infection occurred in the initial wound and in four in the operative wound (in one after open reduction of a longitudinal fracture, in one after extraction of the Rush-pin in one after a graft operation and in one after Kuntscher-nailing)

(2) Skin necrosis Insignificant necrosis of the wound margins was not recognized as necrosis In six fractures superficial necrosis of the skin was observed none required skin transplantation One of these occurred over the fracture as a result of the initial trauma and in five because of pressure from the plaster Three of these occurred in the long leg cast with two appearing at the heel and in one because of pressure after wedging Two skin necroses occurred in the PTB-cast in one probably because of an attempt to correct an angulation during application of the PTB-cast and in the other because of pressure over the fibular head this case also developed a partial peroneal palsy The largest necrosis caused by the PTB-plaster is shown in Fig 10

(3) Peroneal palsy One patient developed a partial peroneal palsy which had recovered completely at follow-up This patient had a long period of lowered consciousness due to a hypercalcemic crisis following an overdose of dihydrotachysterol and calcium-therapy for phenytoin induced osteopenia the absence of an adequate alarm response probably contributed to prolonged hyperpressure with peroneal injury and skin necrosis At the follow-up she also had a cavus deformity of the foot

(4) Thrombo-embolism Clinical evidence of venous thrombosis verified by phlebography occurred in four patients in one of these the thrombosis involved the uninjured leg Two of these four patients had pulmonary embolism and an additional two patients had pulmonary embolism without previous certain diagnosis of thrombosis One of the patients with thrombosis was subjected to ligation of the inferior vena cava thrombectomy and institution of an arterial venous shunt In one of the patients with pulmonary embolism the diagnosis was made on the basis of his verbal account during the re-examination he never sought medical advice during his thrombo-embolic episode

Table XVI

Complications in tibial shaft fractures

	Superficial wound infection	Skin necrosis due to		Peroneal palsy	Thrombosis	Embolism	Delayed union	Loose screws	Total
		Initial contusion	Pressure from the plaster						
Displaced longitudinal closed	1		1	1		2		3	8
Displaced longitudinal open		1			1				2
Displaced transverse closed	4		1		1		6		12
Displaced transverse open	1		3				7		11
Non-displaced transverse closed						2			2
Total	6	1	5	1	2	4	13	3	35

(5) Delayed union i e healing time longer than 20 weeks was observed in seven open and six closed transverse fractures Delayed union was not observed in longitudinal fractures among whom the longest healing time was 18 weeks

(6) Loosening of screws In three longitudinal fractures the screws loosened and the fractures re-displaced somewhat but never to the full preoperative position The fracture with maximal displacement is shown in Fig II

Hospitalization periods (Table XVII)

The mean hospitalization time was 13 days for transverse closed fractures and 14 days for longitudinal and transverse open fractures including hospitalization for secondary procedures However a few patients were hospitalized for a very long time because of concomitant injury or disease, for example two patients with head injury two pelvic fractures, one severe asthma one severe open fracture of the elbow one vertebral fracture one femoral fracture two scapular fractures of which one had a plexus injury one alcoholism one with a hypercalcemic crisis If these patients are excluded the mean hospitalization was 7 days for longitudinal fractures and 11 days for transverse fractures It is thus better to show the median values half of the patients stayed in hospital six days for longitudinal and closed transverse fractures and seven days for open transverse fractures

Table XVII
Days of hospitalization including secondary treatment

	A		B	
Type of fracture	m ± s e m	median	m ± s e m	median
Displaced longitudinal	14 ± 4	6	7 ± 1	6
Displaced transverse closed	13 ± 2	6	11 ± 2	6
Displaced transverse open	14 ± 3	7	11 ± 3	7

A All fractures
B After exclusion of patients with other injury or disease

Healing times (Table XVIII)

The 50 % healing time was 2 8 months for longitudinal fractures 3 1 months for closed transverse fractures and 3 4 months for open transverse fractures The difference between different types of fracture was larger in terms of 95 % healing 4 3 months for longitudinal fractures and 4 8 and 5 9 months for clo ed and open transverse fractures respectively

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	$m \pm s e m$	median	$m \pm s e m$	median
Displaced longitudinal	14 ± 4	6	7 ± 1	6
Displaced transverse closed	13 ± 2	6	11 ± 2	6
Displaced transverse open	14 ± 3	7	11 ± 3	7

A All fractures
B After exclusion of patients with other injury or disease

Healing times (Table XVIII)

The 50 % healing time was 2 8 months for longitudinal fractures 3 1 months for closed transverse fractures and 3 4 months for open transverse fractures The difference between different types of fracture was larger in terms of 95 % healing 4 3 months for longitudinal fractures and 4 8 and 5 9 months for closed and open transverse fractures respectively

Table XVIII

Fracture healing times, this series (months)

Type of fracture	50 % of the group	95 % of the group
Displaced longitudinal	2 8	4 3
Displaced transverse closed	3 1	4 8
Displaced transverse open	3 4	5 9
Non-displaced	1 9	2 5

Disability periods (Fig 3)

The cumulative disability period was determined for those patients who were eligible to sick-pay Excluded from these calculations were thus students, pensioners and one woman who was pregnant After six months 2/5 of the patients with displaced longitudinal and closed transverse fractures and 1/3 of open transverse fractures had returned to their occupations After twelve months these figures were 9/10 and 4/5 respectively *Two patients could not return to their previous occupations, one 58-year old man will probably have a disability pension and a 19-year old man was being re-*trained A 68-year old man was working only half-time in his previous occupation



Fig 3 Disability following tibial shaft fracture

The figure shows fraction returned to work

Results at follow-up (Tables XIX-XXI)

The final result could not be evaluated in one patient with a non-displaced longitudinal fracture because he had previously had a double fracture and the final result was due to his initial fracture

(1) Working capacity All but two patients could return to their previous jobs However as a result of the tibial fracture six patients had some problems when engaged in heavy work

(2) Sports activities Two patients had discontinued sport activities because of the fracture one had continuous pain in the fracture region and one had limited function because of shortening, muscle atrophy and poor ankle motion An additional four patients had diminished their sports activities Two of them did sprinting for exercise but did not play as much soccer as they had previously done one had already previously had a tibial fracture through soccer and did not want to subject himself to the risk of having a third fracture and one patient with a double fracture after he had been hit by a car had some problems which did not allow full sports activity

(3) Walking capacity Two patients had a continuous limp, i e those who had been unable to return to their previous occupations

(4) Pain Two patients had rest-pain in the fracture region One of those had a longitudinal fracture the rest-pain was not aggravated by weight-bearing, he had full working and walking capacity and examination did not reveal the cause One patient had very poor function after a severely comminuted distal fracture of the tibia

(5) Ankle and foot motion Four patients had objective and/or subjective symptoms of poor ankle and foot motion Two patients had severe complaints One of those had a severely displaced open distal fracture with severe soft tissue injury after he had been caught in a machine he had only slightly decreased ankle motion The other patient had a severely comminuted fracture in a traffic accident he had contracture of the foot as described by Karlström et al (1975) with minimal ankle and foot motion One patient had been bone-grafted and treated in plaster for altogether 19 months he had severely limited ankle and foot motion with contracture of the flexor hallucis longus but he had no subjective complaints possibly because of limited activities The fourth patient had a contracted foot following a longitudinal fracture but had no subjective complaints, also in this case probably because of decreased activity the patient was 64-years old and was in very poor general condition

Table XVIII

Fracture healing times, this series (months)

Type of fracture	50 % of the group	95 % of the group
Displaced longitudinal	2 8	4 3
Displaced transverse closed	3 1	4 8
Displaced transverse open	3 4	5 9
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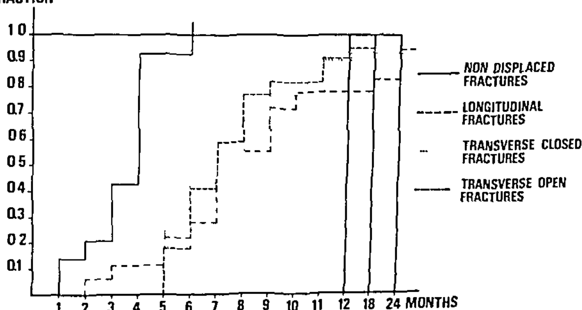


Fig 3 Disability following tibial shaft fracture

The figure shows fraction returned to work

Table XX

Objective signs at follow up of tibial shaft fractures

Type of fracture	Knee motion I	II	III	Ankle motion I	II	III	Foot motion I	II	III	Foot contracture I	II	III	Atrophy I	II	III
Displaced longitudinal closed	23			22	1		18	5		22		1	20	3	
Displaced longitudinal open	5			5			4	1		5			4	1	
Displaced transverse closed	36			35	1		30	5	1	35		1	31	5	
Displaced transverse open	27			26	1		21	5	1	26	1		21	5	1
Non-displaced transverse closed	14			14			14			14			13	1	
Total	105			102	3		87	16	2	102	1	2	89	15	1

Type of fracture	Swelling I	II	III	Shortening I	II	III	Angulation^x I	II	III	Rotational deformity I	II	III
Displaced longitudinal closed	17	4	2	19	4		20	3	1	20	2	1
Displaced longitudinal open	2	3		5			4	1		5		
Displaced transverse closed	33	3		28	6	2	25	8	4	36		
Displaced transverse open	24	1	2	22	4	1	15	10	2	26	1	
Non-displaced transverse closed	14			14			16			14		
Total	90	11	4	88	14	3	80	22	7	101	3	1

x) Including the four patients who were not subjected to follow-up examination

Table XIX

Subjective symptoms at follow-up of tibial shaft fractures

Type of fracture	Working cap			Sports act			Walking cap			Pain			Ankle function			Knee function		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Displaced longitudinal closed	21	2		22		1	19	4		17	5	1	20	3		22	1	
Displaced longitudinal open	4	1		5			4	1		4	1		5			5		
Displaced transverse closed	34	1	1	32	4		35		1	34	1	1	33	2	1	36		
Displaced transverse open	24	3		26		1	22	4	1	24	3		23	3	1	27		
Non-displaced transverse closed	14			14			14			14			14			14		
Total	97	7	1	99	4	2	94	9	2	93	10	2	95	8	2	104	1	

(11) Angulation 80 fractures had no angulation the fracture angle was 5° or less 29 fractures had an angulation of $6-10^{\circ}$ and seven of more than 10° In 16 of these 29 cases the fracture angle had increased by $5.9 \pm 1.3^{\circ}$ during weight-bearing, i e during the period between the X-ray examination immediately after the first PTB-cast had been applied and the final examination The largest angulation was 31°, it had increased 20° during weight bearing This patient was 60-years old and refused to have the angle corrected The second largest angulation was 15°, shown in Fig 12 - In five fractures the angle was open anteriorly, in eight medially (varus) and in 11 antero-medially In three fractures the angle was open posteriorly, in one posterior-medially and in one posterior-laterally - Five of the fractures with angulation of more than 5° were longitudinal (one with encircling wire, two Rush-pins one screwed, and one without osteosynthesis and with a non-fractured fibula) and 24 were transverse (19 with Rush pins and five without osteosynthesis of which three had a non-fractured fibula)

(12) Rotational deformity Malrotation was observed in four fractures but did not seem to cause any complaints The largest malrotation was 30° in a 73-year old man and the next largest 20° in a 70-year old woman permanently confined to a long-term institution

(13) Over-all classifications of the final results (Table XXI) The over-all results in this series of 105 fractures evaluated were 67 % excellent 24 % good 6 % acceptable and 3 % poor However as expected the over-all results in the non-displaced fractures were uniformly excellent The results in the 91 displaced fractures were 57 excellent 24 good 7 acceptable and 3 poor - The results at re-examination of the 17 fractures which had not been subjected to early weight-bearing are shown in the list of coded data The functional result in this group was sometimes impossible to evaluate because of other disease and injury Of the three fractures which by "mistake" were not subjected to early weight-bearing two would had been classified as excellent and one as good

(6) Knee motion All patients had normal knee motion Only one had complaints from the knee, probably unrelated to the fracture This case was a 60-year old man with a longitudinal fracture who after the fracture had healed was operated on for a meniscus lesion and who had clinical evidence of femoro-patellar arthrosis at the re-examination

(7) Additional complaints Five patients complained of pain or discomfort elicited from the scar above the tibial tuberosity at kneeling None of these patients felt that these sensations constituted any major problem One patient had a muscle hernia which felt uncomfortable after excessive walking, he refused surgery of the hernia

(8) Muscle atrophy The circumference of the fractured leg was compared with that of the normal leg On the basis of this comparison 89 legs had a muscle atrophy of less than 1 cm, 15 between 1 and 2 cm and only one more than 2 cm This latter case was an open double fracture with a large soft tissue injury but without any subjective complaints

(9) Swelling Swelling was evaluated by comparison of the circumference just proximal to the ankle joint of both legs 90 legs had swelling of less than 1 cm, 11 between 1 and 2 cm and four more than 2 cm The largest swelling was 4 cm in a patient who had had a longitudinal fracture This patient had marked varicosities bilaterally and had been operated on for this reason on the non-fractured side Of the 11 patients with moderate swelling one had had thrombosis of the contralateral leg None of the other three patients with phlebographic evidence of thrombosis had any swelling on re-examination

(10) Shortening 88 legs had shortening of less than 1 cm, 14 had shortening of 1-2 cm and three had shortening of more than 2 cm Of the 14 legs with moderate shortening, six occurred after longitudinal or short oblique fractures (four without osteosynthesis and two with Rush-pins), eight occurred in transverse fractures which had either delayed healing, were comminuted or double (six of these had a Rush-pin, one was transfixed and one was treated without osteosynthesis) In two of these cases the fibula was not fractured but they had healed in varus and the leg length was measured between the medial joint line of the knee and the tip of the medial malleolus Of the three legs with shortening of more than 2 cm, two had double fractures with 2 5 cm shortening and one with 3 5 cm of shortening had a severe comminuted fracture which healed only after grafting the primary treatment in all these three fractures was by Rush-pinning

(11) Angulation 80 fractures had no angulation the fracture angle was 5° or less 22 fractures had an angulation of 6-10° and seven of more than 10° In 16 of these 29 cases the fracture angle had increased by 5 9 ± 1 3° during weight-bearing i e during the period between the X-ray examination immediately after the first PTB-cast had been applied and the final examination The largest angulation was 31° it had increased 20° during weight-bearing This patient was 60-years old and refused to have the angle corrected The second largest angulation was 15° shown in Fig 12 - In five fractures the angle was open anteriorly in eight medially (varus) and in 11 antero-medially In three fractures the angle was open posteriorly in one posterior-medially and in one posterior-laterally - Five of the fractures with angulation of more than 5° were longitudinal (one with encircling wire two Rush-pins one screwed and one without osteosynthesis and with a non-fractured fibula) and 24 were transverse (19 with Rush pins and five without osteosynthesis of which three had a non-fractured fibula)

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Table XXI

Over-all results at follow-up of tibial shaft fractures

Type of fracture	Excellent	Good	Acceptable	Poor	Total
Displaced longitudinal closed	12	7	3	1	23
Displaced longitudinal open	2	3			5
Displaced transverse closed	26	9		1	36
Displaced transverse open	17	5	4	1	27
Non-displaced transverse closed	13	1			14
Total	70	25	7	3	105
%	(67%)	(24%)	(6%)	(3%)	

V DISCUSSION

A useful program for treatment of tibial fractures should be applicable to the majority of these fractures but it need not include fractures with severe soft tissue problems due to arterial injury, nerve injury extensive skin damage, etc and it need not include patients with multiple injuries Based on the morbidity observed here the program tested in this investigation was applicable to some 90 % of all cases of fracture of the tibia in adults Furthermore the program for treatment of tibial shaft fracture should be sufficiently simple not to require specialized experience, because the everyday run of tibial shaft fractures are treated in peripheral hospitals complications following treatment with the AO-compression methods have been explained as due to insufficient expertise (Thunold et al 1975) The program should ensure a low incidence of complications, especially serious complications, it should require as few active interventions as possible short hospitalization and minimal convalescence, and the end result should compare with more complicated methods

The results of this investigation will be compared here with Edwards s (1965) prospective series (the Malmö series) and Olerud and Karlström s (1972a) five year material of tibial shaft fractures treated with the AO-compression plate (the Uppsala series) I have chosen these materials for comparison because they are recent and they are based on similar demographic and epidemiologic environments In fact, the composition of the three series is almost identical with a dominance of high energy fractures caused by traffic accidents However in the Malmö series there was an overrepresentation of extensive soft tissue injury referred from a wide area The Uppsala series did not contain a similar proportion of severe soft tissue injury, perhaps because Olerud and Karlström (Olerud 1973 Karlström and Olerud 1975) preferred to use transfixation with the Vidal-Adrey method in such cases However the classification of soft tissue injury in the Uppsala series differs from that used in the Malmö series and in this investigation a close comparison with the Uppsala series is therefore not feasible

In principle the primary treatment in the Malmö series was the same as here a comparison between these materials should show whether early weight-bearing in the PTB-cast had an influence on the end result The therapeutic principles applied to the Uppsala series on the other hand, were entirely different a comparison should permit an analysis not only of the end results but also of the entire healing course It would have been desirable to compare these series with a series of tibial shaft fractures not subjected to open treatmen but only to early weight-bearing However, the series of cases published by Dehne et al (1961) Brown and Urban (1969) Sarmiento (1967 1970 1974)

Broström and Eriksson (1970), Lambding (1973), Balkfors (1974), Burkhalter and Protzman (1975), King (1975), Wiedmer and Bianchini (1975), Rosentahl et al (1977), Suman (1977) were either selected or subjected to incomplete follow-up, they have not been described in sufficient detail to permit more than isolated comparisons

Complications

In this series the majority of the complications were moderate, they did not require e-condary interventions and they did not prolong the periods of hospitalization or treatmen Serious complications, to be discussed here, are thrombosis, embolism, deep infection with osteomyelitis, and delayed union requiring secondary operations The incidence of serious complications in this material was 14 % with 6/37 in closed transverse fractures and 4/27 in open transverse fractures By comparison with the Uppsala series, the total absence of osteomyelitis in this series was significant ($p < 0.05$) and this was true also of the total number of complications ($p < 0.05$) even though the definition of delayed union used here probably was somewhat stricter than the one used in Uppsala, in the Uppsala material about 1/4 of the patients were not allowed full weight-bearing until after 20 weeks

(I) Thrombosis and embolism Thrombosis was not recorded in the Malmö, Uppsala and Sarmiento (1974) series of 482 fractures However, several authors (Hjelmstedt and Bergva 1968, Nylander and Semb 1972, Vogl et al 1972) have shown by phlebography that the incidence of deep thrombosis is high indeed in tibial fractures Hjelmstedt and Bergvall (1968) found an incidence of 54 % in patients over 25 years with a significantly higher incidence in patients treated with internal fixation and a plaster cast as compared to those treated with a cast only Vogl et al (1972) found a lower incidence of deep thrombosis, like Olerud and Karlström (1972a) they treated the fractures with vacuum drainage and early motion Possible the drainage and early motion in the Uppsala series explains the virtual absence of thrombo-embolism recorded there, whereas in this series the incidence was 5 % ($p < 0.01$) However there was no difference between the Uppsala series and this series as regards the incidence of ankle or lower-leg oedema in the Malmö series this sequel to deep thrombosis was not recorded separately and Sarmiento (1974) has not published any follow-up of his patients

In this series the patients did not receive any prophylactic treatment against thrombosis Because of the high incidence of thrombo-embolism in fractures of the hsaft of the tibia and because of the common complaint of a chronic swelling following these fractures routine treatment with Macrodex[R] (Bergentz 1975) should perhaps be recommended in patients over 20 years of age The severity of the fracture does not necessarily indicate the need for such prophylactic treatment, two of the thrombo-embolism cases in this series were non-displaced transverse fractures in patients aged 24 and 44 years

(2) Osteomyelitis In this series osteomyelitis did not occur and in the Malmö series only one case occurred in 109 displaced transverse fractures By contrast in the Uppsala series the over-all incidence of osteomyelitis was 5 % and of "metallosis" 10 % The majority of the osteomyelitis cases occurred in the transverse fractures and in particular among the 38 open transverse fractures 6 of which had this complication The marked difference in incidence of osteomyelitis between this series and the Malmö series on one hand and the Uppsala series on the other is probably related to soft tissue and skin injury after the skin has been exposed to high energy trauma it does not tolerate the additional injury associated with the exposure for plate osteosynthesis (Edwards 1965, Bauer and Hulth 1973)

The conservative attitude toward the handling of skin and soft tissues basic to this investigation has been applied in earlier materials e g Zucman and Maurer (1969, 1970) Merle d Aubigné et al (1974) Lottes (1974), Harvey et al (1975) These materials also had a low incidence of osteomyelitis With the reservation that the distinction between wound infection and osteomyelitis was not always clearly defined the incidence of wound infection in open fractures seemed to be somewhat higher than in this and in the Malmö series

(3) Delayed union The concept delayed union is hard to define the time limit of 20 weeks (Nicoll 1964) represents more a conventional than a biologically meaningfull parameter The time limit 20 weeks may still be useful first to permit a comparison with other materials and second e g in this investigation as an indication when unnecessarily prolonged treatment may be avoided by institution of secondary procedures

The proponents of early weight bearing in the treatment of fractures of the tibia have always argued that the healing course is promoted by such more physiological treatment (Borelius 1894 Gurd 1940 Dehne 1974 Sarmiento 1974) However, the analysis or presentation of fracture materials treated by early weight-bearing does not seem to permit this conclusion Sarmiento (1967, 1970 1974) has published values for the mean healing time in different types of tibial fractures but not the incidence of delayed healing In his 1974 publication he had only two cases of pseudarthrosis in 482 fractures In the series of open fractures of the tibial shaft treated with early weight-bearing published by Brown and Urban 1969 the time in plaster was longer than 20 weeks in 23 of 63 cases Rosentahl et al (1977) treated 60 open tibial fractures with early weight-bearing a pseudarthrosis operation was performed in ten of these cases six of whom however were infected Nicoll (1964) has carefully studied the incidence of delayed healing in a series of tibial fractures treated with closed methods without weight-bearing he found an incidence of delayed union of 21 % in non-infected displaced fractures, ranging from 9 % in simple fractures to 39 % in severe fractures In this series the incidence

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Table XXII
Fracture healing times (months)

Type of fracture	This series 50%	95%	Malmö series 50%	95%	Brown 50%	Urban (1969) 95%
Displaced longitudinal	2 8	4 3	2 2	3 5		
Displaced transverse closed	3 1	4 8	3 1	9 0		
Displaced transverse open	3 4	5 9	4 5	14 0	4 2	8 2

The Malmö series refers to the prospective series published by Edwards (1965)

In my opinion the weight of evidence suggests that early weight-bearing may have a favourable effect on the healing of fracture of the shaft of the tibia However early weight-bearing certainly does not guarantee healing

Secondary operations

The incidence of secondary operations in this series (11 %) was significantly (p < 0 01) lower than in the Uppsala series (22 %) but the same as in the Malmö series (13 %) The relatively high incidence of secondary operations in the Uppsala series correlates with the incidence of complications common in fractures treated with the compression plate notably osteomyelitis broken plates and refractures

Hospitalization periods (Table XXIII)

The periods of hospitalization in this series were shorter (p < 0 05 for longitudinal and transverse open fractures p < 0 01 for transverse closed fractures) than in the Uppsala series notably in the transverse closed fractures in which the median period of hospitalization in the Uppsala series was three times as long as in this series this difference is explained by the relatively high incidence of secondary operations in the Uppsala series However the hospitalization periods were short in this series also when compared to the Malmö prospective series even though both series had a low incidence of complications At least in part the difference between this series and the Malmö series may be due to the general trend toward shorter periods of hospitalization during the 15 years which have elapsed between the two series

The philosophy basic to this series included the aim of providing definitive treatment as early as possible preoperative traction was rarely used The majority of cases subjected to internal fixation were operated on within 24 hours (Table IX) As regards utilization of hospital beds the program for treatment used in this series would thus be

of non-union was 14 %, i e significantly ($p < 0.05$) lower than in the Nicoll (1964) series

Edwards and Nilsson (1965) analysed the course of healing in the Malmö series by graphic probit analysis, the regression line for the course of healing obtained with this method does not suffer from undue influence of isolated extreme values The healing times in this series were compared to those in the Malmö and Brown and Urban (1969) series (Table XXII) In longitudinal fractures the healing times were significantly ($p < 0.01$) shorter in the Malmo series than in this series The explanation for this may be that the proportion of fractures subjected to stable osteosynthesis with screws was higher in this series, following stable osteosynthesis the clinical evaluation of the fracture healing is difficult, little visible callus is formed, and therefore the period of plaster cast fixation was rarely shorter than 12 weeks

As regards healing time in the displaced transverse fractures there was no difference between the Malmö and this series in terms of 50 % healing, but a difference in 95 % healing This difference was largest in the open fractures where the 95 % healing time in this series was only half of that of the Malmo series This difference may be due to the higher proportion of large skin wounds in the Malmö series The data were corrected for this difference by exclusion from the Malmo series of all fractures with wounds larger than 10 cm the 50 % and 95 % healing times in the Malmo series were now calculated to be 4 2 and 9 9 months, still longer than the 3 4 and 5 9 months values recorded in this series When the Brown and Urban (1969) series of open fractures was subjected to the same probit analysis a similar pattern was observed, the 95 % healing time was shorter than in the Malmö series in spite of the fact that the Brown and Urban cases were war injuries with probably more comminution and more extensive soft tissue injury than in the Malmo series of civilian fractures This comparison of the Brown and Urban (1969) and this series with the Malmo series would indicate that early weight-bearing does indeed shorten the healing time However in a series of 97 tibial fractures treated with closed methods and early weight-bearing in a PTB-plaster, Balkfors (1974) did not find any difference in healing times as compared to the Malmö series This observation need not be valid because the treatment with PTB-cast was handled by a large number of surgeons and the patients were evaluated at six week intervals (Balkfors 1977)

Analysis of the variance of healing times for displaced transverse fractures revaled a significant ($p < 0.05$) difference between this series and the Malmo series for open as well as closed fractures However, if the eleven cases with major soft tissue wounds in the Malmo series are discounted the difference between the two series for open transverse fractures has only borderline significance

Results of follow-up

Final evaluation of the treatment of fracture of the tibia must take into account both functional and anatomic parameters if the two are confused evaluation is invalidated Moderate shortening and/or angulation usually does not cause any inconvenience or impaired function In terms of function it would thus not be reasonable to avoid such anatomic imperfections at the risk of a higher incidence of serious complications Osteosynthesis with a compre sion plate is advocated in order to achieve a better end result than that obtainable with closed reduction and plaster (Olerud and Karlström 1972a) Whether this can indeed be achieved will be discussed here on the basis of a comparison of this series with the Uppsala series

(1) Joint stiffness The proponents of compression plate osteosynthesis believe that primary plaster fixation causes joint stiffness especially in the ankle (Müller et al 1970 Olerud and Karlström 1972a Karlström and Olerud 1974) However the incidence of joint stiffness was nearly the same in the Uppsala series as in this series On the other hand in this series the stiffness was usually located below the astragalus which was never observed in the Uppsala series At any rate some residual ankle joint stiffness seems to be common following tibial fracture probably due to ischaemic muscle damage (Ellis 1958 Owen and Tsimboukis 1967 Karlström and Olerud 1974 Karlström et al 1975) i e the compartment syndrome (vide infra) rather than an effect of plaster fixation on the joints per se The residual cavus deformity of the foot which severely impairs function has been thoroughly analyzed by Karlström et al (1975)

(2) Atrophy There was no difference between this series and the Uppsala series as regards muscle atrophy Possibly early weight-bearing stimulates muscle function to the same degree as does early motion

(3) Shortening The use of early weight-bearing has been criticized as a cause of shortening n fractures of the tibia Sarmiento (1974) has demonstrated that early weight-bear ng does not increase the initial shortening When the initial shortening is not deemed acceptable he has recommended transfixation to restore the length Brown (1974) was more conservat ve he felt that shortening was a small price for obtaining uncomplicated healing Dehne et al (1961) examined the shortening in a 12 % sample of his tibial fractures 2/5 of these fractures had a shortening of 1 3 - 1 9 cm

The reason to perform an o teosynthesis in this series was to decrease the final shortening Accepting Sarm ento s (1974) statement that without osteosynthesis the final shortening equals the nitial shortening these variables were measured In the longitudinal fractures treated w th screws the mean gain was 9 mm and the maximal gain 20 mm In the short

preferable to the one published by Olerud and Karlström (1972b) which requires first open reduction and osteosynthesis with a compression plate, and then, as a secondary operation removal of the plate and medullary nailing Other examples of seemingly unnecessary prolongation of the hospitalization period are the recommendations to perform delayed internal fixation (Solheim 1973, Smith 1974, Allgöwer 1975, Langård and Bø 1976, Jensen et al 1977), apparently in an attempt to avoid the high incidence of complications following early primary osteosynthesis with the compression plate in high energy fractures

Table XXIII

Days of hospitalization for tibial shaft fractures, median values

Type of fracture	This series	Uppsala series	Malmö series
Displaced longitudinal	6	12	14
Displaced transverse closed	6	20	14
Displaced transverse open	7	18	35

The Malmo series refers to the prospective series published by Edwards (1965)
The Uppsala series refers to Olerud and Karlström (1972a)
The periods of hospitalization shown here include secondary treatment

Disability periods

The period of disability is an uncertain and poor measure of the results of treatment of fractures of the tibia, even comparisons in the same community and during the same period of time may be invalid because of undefinable circumstances As compared to this series, the Uppsala series had a somewhat higher number of patients back to work within six months but somewhat fewer at 12 months There was not much difference in this respect between this series and the Malmo series except in open transverse fractures, at 12 months 2/3 of the patients here had returned to work and only about one half in Malmö, this difference was significant ($p < 0.05$) but may be due to the higher incidence of extensive soft tissue injury in the Malmö series

With due regard to the difficulties in comparing disability periods the data discussed here may indicate that rehabilitation in non-complicated cases of compression plate treated tibial fractures is somewhat more rapid than in those treated in a plaster cast However, the higher incidence of complications following compression plate fixation results in an increased number of patients with very long periods of disability

Results of follow-up

Final evaluation of the treatment of fracture of the tibia must take into account both functional and anatomic parameters if the two are confused evaluation is invalidated Moderate shortening and/or angulation usually does not cause any inconvenience or impaired function In terms of function it would thus not be reasonable to avoid such anatomic imperfections at the risk of a higher incidence of serious complications Osteosynthesis with a compression plate is advocated in order to achieve a better end result than that obtainable with closed reduction and plaster (Olerud and Karlström 1972a) Whether this can indeed be achieved will be discussed here on the basis of a comparison of this series with the Uppsala series

(1) Joint stiffness The proponents of compression plate osteosynthesis believe that primary plaster fixation causes joint stiffness especially in the ankle (Müller et al 1970 Olerud and Karlström 1972a Karlström and Olerud 1974) However the incidence of joint stiffness was nearly the same in the Uppsala series as in this series On the other hand in this series the stiffness was usually located below the astragalus which was never observed in the Uppsala series At any rate some residual ankle joint stiffness seems to be common following tibial fracture probably due to ischaemic muscle damage (Ellis 1958 Owen and Tsimboukis 1967 Karlström and Olerud 1974 Karlström et al 1975) i e the compartment syndrome (vide infra) rather than an effect of plaster fixation on the joints per se The residual cavus deformity of the foot which severely impairs function has been thoroughly analyzed by Karlström et al (1975)

(2) Atrophy There was no difference between this series and the Uppsala series as regards muscle atrophy Possibly early weight-bearing stimulates muscle function to the same degree as does early motion

(3) Shortening The use of early weight-bearing has been criticized as a cause of shortening in fractures of the tibia Sarmiento (1974) has demonstrated that early weight-bearing does not increase the initial shortening When the initial shortening is not deemed acceptable he has recommended transfixation to restore the length Brown (1974) was more conservative he felt that shortening was a small price for obtaining uncomplicated healing Dehne et al (1961) examined the shortening in a 12 % sample of his tibial fractures 2/5 of these fractures had a shortening of 1 3 - 1 9 cm

The reason to perform an osteosynthesis in this series was to decrease the final shortening Accepting Sarmiento s (1974) statement that without osteosynthesis the final shortening equals the initial shortening these variables were measured In the longitudinal fractures treated with screws the mean gain was 9 mm and the maximal gain 20 mm In the short

preferable to the one published by Olerud and Karlström (1972b) which requires first open reduction and osteosynthesis with a compression plate, and then, as a secondary operation removal of the plate and medullary nailing Other examples of seemingly unnecessary prolongation of the hospitalization period are the recommendations to perform delayed internal fixation (Solheim 1973, Smith 1974, Allgöwer 1975, Langård and Bø 1976, Jensen et al 1977), apparently in an attempt to avoid the high incidence of complications following early primary osteosynthesis with the compression plate in high energy fractures

Table XXIII

Days of hospitalization for tibial shaft fractures, median values

Type of fracture	*This series*	*Uppsala series*	*Malmö series*
Displaced longitudinal	6	12	14
Displaced transverse closed	6	20	14
Displaced transverse open	7	18	35

The Malmö series refers to the prospective series published by Edwards (1965)

The Uppsala series refers to Olerud and Karlström (1972a)

The periods of hospitalization shown here include secondary treatment

Disability periods

The period of disability is an uncertain and poor measure of the results of treatment of fractures of the tibia, even comparisons in the same community and during the same period of time may be invalid because of undefinable circumstances As compared to this series, the Uppsala series had a somewhat higher number of patients back to work within six months but somewhat fewer at 12 months There was not much difference in this respect between this series and the Malmö series except in open transverse fractures, at 12 months 2/3 of the patients here had returned to work and only about one half in Malmö, this difference was significant ($p < 0.05$) but may be due to the higher incidence of extensive soft tissue injury in the Malmö series

With due regard to the difficulties in comparing disability periods the data discussed here may indicate that rehabilitation in non-complicated cases of compression plate treated tibial fractures is somewhat more rapid than in those treated in a plaster cast However, the higher incidence of complications following compression plate fixation results in an increased number of patients with very long periods of disability

Table XXIV

Progression of deformity in tibial shaft fractures

	≤5°	6-10°	>10°
Postoperative	12	17	
After first PTB-cast	12	16	1
After 3 weeks of weight-bearing	4	21	4
After 9 weeks of weight-bearing	2	22	5
Final angulation		22	7

As regards the direction of angulation it appeared that early weight-bearing had a general tendency to cause a varus angle but other types of angulations were also observed There did not seem to be any correlation between fracture level and risk or type of angulation

It appears from this investigation that early weight-bearing is definitely accompanied by a risk for angulation which one should be prepared to prevent and treat activelv All angulations should be corrected a early as possible even those which seem acceptable after a period of weight-bearing the angle may increase and it may soon prove difficult to correct It is simple to wedge the long-leg cast especially when the true angle and its direction have been determined There should be no reason to accept an initial angulation of 15° as proposed by Wyman and Barr (1974) In this way the incidence of angulation should decrease considerably Only one of those which developed severe angulation started weight-bearing with a truly straight tibia, this wa a proximal fracture with a non-fractured fibula In another two short oblique fractures with non-fractured fibulas the varus angles were corrected by wedging but they recurred when the PTB-plaster was applied and they then increased during weight-bearing

(5) Over-all results (Table XXV) The functional over-all results were similar and generally favourable in the three series compared here It is true that the Uppsala series was somewhat better than the Malmö series but this was very probably due to the high incidence of open transverse fractures in the latter series after exclusion of the cases with major soft tissue injury (wound size larger than 10 cm) the end results in the Malmö series were comparable to the other series Indeed if one can achieve a low incidence of complications the functional end results seem to correlate more with the initial injury than with the type of treatment It is in fact remarkable that the high incidence of complications in the Uppsala series did not adversely influence the end result these facts suggest that the infected fractures were treated with a high degree of expertise

oblique and comminuted transverse fractures treated with a Rush-pin the mean gain was 8 mm and the maximal gain 34 mm

The reason why osteosynthesis with the Rush-pin did not always prevent shortening was that the pin did not fit the entire circumference of the marrow cavity, a slight dislocation to the side therefore occurred, sometimes associated with shortening in oblique and comminuted fractures (Fig 6)

Moderate shortening is usually not much of a problem if the function is otherwise good It therefore does not seem indicated to subject the patients to an increased risk of complications solely to avoid shortening However, there seems to be no reason to accept shortening if it can be avoided at no or little risk as demonstrated in this series

(4) Angulation At follow-up a high incidence of angulation was recorded This problem seems to have been minimized by the proponents of weight-bearing and was therefore not identified in this investigation until at the time of follow-up Brown and Urban (1969) found an angulation up to 15° in 44 of 63 fractures Dehne et al (1961) measured the fracture angles in 27 consecutive fractures in a total of 221 fractures, twelve of the 27 fractures had angulation, but not more than 10°, the authors concluded that angulation does not constitute a problem but in their figure 2C the angulation measured is about 17° Gamble et al (1972) found angulations of more than 5° in 20 % of their cases Sarmiento (1974) reported 9 % angulation over 5° with maximal angulation of 12° In all of the above publications the angulation has been measured only in AP and lateral X-rays projections, the true angulation may thus have been underestimated

The high incidence of final angulation in this series was not always due to early weight-bearing In seven cases an angulation seen in the immediate postoperative X-ray was caused by undue bending of the Rush-pin before insertion In 18 fractures the angulation increased after the primary treatment and in 16 of those the increased angulation occurred during weight-bearing (Table XXIV) In ten fractures the angle increased less than 4° but in eight fractures it increased more than 7° and up to 23° In three of these latter fractures the angle increased gradually until it was observed only when the fracture had healed (Fig 13), in three fractures the fibula was not fractured, one fracture had very slow healing and one fracture occurred in a patient who was a chronic alcoholic and left the hospital without waiting for correction of the angulation which occurred after the long-leg cast had been changed to a PTB-cast

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into open and closed fractures 43 % of the cases were ski injuries the good prognosis in this type of fractures is well known (Infanger et al 1971 van der Linden et al 1975) In the 95 open fractures 23 severe complication occurred 11 of these osteomyelitis Among the open fractures 39 were probably after indirect trauma as the wounds were caused by simple piercing of the skin from within the majority of the complications probably occurred in the other 56 fractures It therefore seems reasonable to agree with Olerud s and Karlström s statement that the compression plate method is not suitable as a routine method in tibial shaft fractures (Olerud and Karlstrom 1972a, Karlstrom 1976)

The compartment syndrome

In this series one patient with a compartment syndrome received adequate treatment by early fasciotomy the functional end result was excellent In three patients active treatment of a compartment syndrome was not instituted all had poor end results In addition a patient who was never treated with early weight-bearing and PTB-plaster had a comminuted proximal fracture of the tibia with arterial injury in spite of fasciotomy and repair of the artery he had a Volkmann contracture resulting in a contracted foot probably because the arterial injury was repaired too late

The compartment syndrome and its serious effect on the end results in fractures of the tibia has been known for a long time and it has been well described in numerous publications (Volkmann 1881 Ellis 1958a Seddon 1966 Willhoite and Moll 1970 Sundén and Wiberg 1971 Fowler and Willis 1975 Holden 1975 Karlstrom et al 1975, Matsen and Clawson 1975 Rorabeck and MacNab 1976) The importance of treating the compartment yndrome has been well documented (Ernst and Kaufer 1971, Feagin and White 1973 Patman et al 1973 Sheridan and Matsen 1976) and seemingly reliable diagnostic methods based on mea urements of the intramuscular pressure have recently been published (Whitesides et al 1975 Matsen et al 1976 Mubarak et al 1976) One may ask why the diagnosis of compartment syndrome is still often not made and even when it is the patients often do not receive adequate treatment However it is not easy to routinely measure the intramuscular pressure it is not enough to measure it once but it should be measured repeatedly or continously and in all the four compartments There is a great need for simple and routinely useful methods for early diagnosis and treatment of the compartment syndrome This series has confirmed Edwards s (1965) demonstration that osteomyelitis is a virtually avoidable complication in fractures of the tibia Olerud and Karlström (1972a) have demon trated that osteomyelitis can be *treated* so successfully that it does not jeopardize a favourable end result Intramedullary reaming and nailing has been repeatedly shown to be a reliable method in the treatment of non union (Christensen 1973) The compartment syndrome remains as the last unsolved threat to uniformly good end results in tibial fractures

One may argue that the over-all evaluation should include also non-symptomatic anatomic imperfections such as angulations In the displaced fractures the sum of all parameters gave 38 % excellent, 46 % good, 13 % acceptable and 3 % poor, the aggregate excellent-good thus was about the same as when function only was evaluated

Few authors have attempted to compare the end results of closed and open treatment of fractures of the tibia in one and the same investigation Karaharju et al (1975) have compared two such groups and their conclusions agreed with the observations here, there was little difference in end result between the two groups but a significant difference in the incidence of complications

Table XXV

Classification of final status at follow-up of displaced tibial shaft fractures

Fracture type	Malmö series	Uppsala series	Present series
Longitudinal			
Excellent-good	41	42	24
Fair-poor	4	1	4
Transverse, closed			
Excellent-good	54	39	35
Fair-poor	8	3	1
Transverse, open			
Excellent-good	32	25	22
Fair-poor	10	6	5
Total			
Excellent-good	127 (85%)	106 (91%)	81 (89 %)
Fair-poor	22 (15%)	10 (9 %)	10 (11%)

The Uppsala series refers to Olerud and Karlström (1972a)

The Malmö series refers to prospective series of Edwards (1965)

The comparisons done here between this series and the Malmo series and the Uppsala series presuppose that the latter represents the AO-compression plate method An analysis of other publications based on that method (Rittman et al 1970 Ketenjian and Shelton 1972, Gallinaro et al 1973 Solheim 1973, Thunold et al 1975) confirms that the Uppsala series is indeed representative However, it has been stressed that the AO-methods require a technical expertise and that the complications are due to technical failures (Thunold et al 1975) The series of fractures from the University Hospital in Basel (Ruedi et al 1975), where the AO-methods are very well known had a high incidence of serious complications in open fractures The fractures were classified only

into open and closed fractures 43 % of the cases were ski injuries the good prognosis in this type of fractures is well known (Infanger et al 1971 van der Linden et al 1975) In the 95 open fractures 23 severe complications occurred 11 of the e osteomyelitis Among the open fractures 39 were probably after indirect trauma as the wounds were caused by simple piercing of the skin from within the majority of the complications probably occurred in the other 56 fractures It therefore seems reasonable to agree with Olerud s and Karlström s statement that the compression plate method is not suitable as a routine method in tibial shaft fractures (Olerud and Karlström 1972a, Karlström 1976)

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Ipsilateral fractures of the femur and the tibia

In this series only four cases had an ipsilateral femoral fracture Only one of these could bear weight early in a PTB-cast, the femoral fracture was treated by intramedullary reaming and nailing Another femoral fracture was treated in the same way but the patient had a head injury and an unstable pertrochanteric femoral fracture of the contralateral side which delayed mobilization One femoral fracture was treated with a compression plate and could therefore not bear full weight (Hansson et al 1977) and one was treated in traction for six weeks and the patient was then mobilized with a cast brace

Several authors feel that ipsilateral fracture of the femur constitutes an indication for compression plate osteosynthesis of a tibial fracture (Nicoll 1974, Hojer et al 1977, Karlstrom and Olerud 1977), early mobilization and better end results would be worth the increased risk of complications However, the PTB-cast allows early motion of the knee and if the femoral fracture permits reaming and intramedullary nailing the patient can be mobilized earlier with full weight-bearing than with a plate osteosynthesis which does not allow weight-bearing

The discomfort to the patient

Few authors have compared different methods of treatment of fracture of the tibia in terms of comfort or rather discomfort to the patients From the start, this investigation aimed at making Edwards s (1965) method more comfortable to the patient without jeopardizing the end result The majority of the patients tolerated the PTB-cast well it was unpadded but it was applied only after the initial swelling had disappeared In fact all patients were satisfied with the PTB-cast and a few returned to their occupations in the cast The majority learned to walk with or without a cane A movable knee permits the patient to sit in the back-seat of a car, in the cinema theater etc Under special circumstances the PTB-cast permits driving a car and a movable knee makes sexual intercourse easier (Brown 1974)

Practical recommendations

1 In order to diminish the risk of shortening by displacement of the fracture a thick intramedullary pin should be chosen so that the medullary cavity is adequately filled

2 Do not bend the pin so much that the fracture angulates forward it should be bent only so that it obtains the shape of a Kuntscher nail If it is necessary to bend the distal end of the Rush-pin in order to find the entrance to the medullary cavity in the distal fragment it is sufficient to bend the last three cm only A thin Kuntscher nail can be used instead of a Rush-pin

3 All postoperative angulations should be corrected by wedging the long-leg cast as soon as possible Po toperative malrotation can be corrected by a transverse circumcision of the plaster and rotation of the distal fragment within the plaster

4 After the patient has been bearing full weight in the PTB-cast the po ition of the fracture should be checked by X-ray not later than at two weeks if the fracture does not have any tendency to angulate further checks can be postponed until every fourth or sixth week

5 The exact angulation should be determined at each X-ray examination it is not enough by eye measurement alone

6 If the patient is comfortable in the PTB-cast it need not be changed unless checking for clinical evidence of healing

VI CONCLUSIONS

On the strength of the material presented here and in the light of earlier publications the following may be concluded concerning the treatment of the vast majority of fractures of the leg in adults

1 Reduction and osteosynthesis with screw(s) in longitudinal fractures or intramedullary nailing in transverse fractures reduce the risk of shortening of the tibial shaft fracture

2 In longitudinal fractures open reduction and osteosynthesis with screw(s) is associated with but little risk for local complications Screw fixation does not preclude early weight-bearing in the PTB-cast

3 In transverse fractures closed reduction and intramedullary fixation with a Rush-pin does not increase the risk for necrosis of the skin and osteomyelitis After intramedullary nailing transverse fractures are well suited for early weight-bearing in a PTB-cast

4 Early weight-bearing in a PTB-cast is recommended as the routine method in the majority of tibial shaft fractures

5 Early weight-bearing may increase the angulation, weight-bearing should not be permitted until angulation has been corrected

6 Early weight-bearing probably favours healing of transverse fractures

7 The functional end result following early weight-bearing in a PTB-cast compares well with other methods and is more comfortable to the patient

8 The compartment syndrome remains an important practical problem in the treatment of fractures of the leg

VII SUMMARY

A Purpose of this investigation

The purpose of this prospective investigation was to test whether the active primary treatment of tibial shaft fractures practised by Edwards (1965) could be combined with early weight-bearing in the PTB-cast practised by Sarmiento (1967)

B Case Material

The material consisted of 105 patients with 110 fractures of the tibial shaft 17 fractures were not displaced and 93 displaced 29 of the displaced fractures were longitudinal of which five were open and 64 were transverse, of which 27 were open 55 of the displaced fractures were caused by high energy trauma mainly traffic accidents

C Treatment

Primary definitive treatment was provided as soon as possible In 10 fractures the operation was delayed 24 hours or more mainly because of concomitant injury or disease

(1) Displaced longitudinal fractures Open reduction and osteosynthesis were performed when the displacement was deemed unacceptable In 18 fractures the osteosynthesis was carried out with screw(s) and in one fracture an encircling wire was used Ten fractures were reduced by clo*ed methods in five of these blind intramedullary nailing with a Rush-pin was performed In the five open fractures the wound was closed with primary suture

(2) Transverse fractures Non-displaced fractures and displaced fractures which could be reduced to a stable position were treated with a long-leg cast only If stable fixation could not be obtained blind nailing with a Rush-pin was performed In comminuted f actures where the Rush pin did not give sufficient stability transfixation in plaster was made In 18 fractures the displacement was reduced to a stable position without osteosynthesis In 43 fractures fixation was obtained with a Push-pin One short oblique fracture was stabilized with a screw Transfixation was used in two comminuted fractures - In all 27 open fractures the wounds were sutured primarily with a relaxing incision in only one fracture Antibiotics were used in all open fractures

(3) Plaster fixation All fractures were initially stabilized with a long-leg plaster and the patients were mobilized with crutches without weight-bearing as soon as possible

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Stiftelsen Konsul Thure Carlssons Minne

After 2-3 weeks the plaster was changed to a PTB-cast, if wound healing and swelling permitted The patients were encouraged to bear full weight in the PTB-cast

D Complications

There were 20 minor and 15 severe complications The severe complications were 9 fractures with delayed healing requiring secondary operations and 6 thrombo-embolic non-fatal episodes There was no case of osteomyelitis in the series

E Final Status

In 96 % of the fractures the final status was determined at 1/2 - 3 1/2 years following the accident The radiographic material was re-examined with regard to malalignment

(1) Function The over-all results were 67 % excellent 25 % good, 6 % acceptable and 3 % poor The results in the 91 displaced fractures were 57 excellent, 24 good, 7 acceptable and 3 poor

(2) Malalignment The re-examination of the radiographic material revealed a high frequency of angulation 22 fractures had an angulation of 6-10° and seven more than 10° In 16 of these 29 cases the fracture angle had increased by 5,9 ± 1,3° during weight-bearing - Shortening of more than one cm was found in 17 fractures

F Comparison with previous investigations

The results of this investigation were closely compared with Edwards s (1965) prospective series and Olerud and Karlstrom s (1972a)review of tibial fractures treated by AO-compression osteosynthesis There were only small differencies between the three series regarding the final functional status Compared with the AO-series there was a lower frequency of both minor and serious complications fewer secondary operations and shorter hospitalization times As in Edwards s series osteomyelitis had been prevented, but the transverse fractures seemed to heal more rapidly

G Conclusion

It was concluded that the methods of treatment used here give a final result comparable to any other method, but with less discomfort to the patient However any angulation should be corrected before weight-bearing is permitted The compartment syndrome remains an important practical problem in the treatment of fractures of the leg

A B C

Fig 6 Double fracture of the tibial shaft treated with open reduction and fixation with a Rush-pin

Case 93 A On admission B After open reduction and fixation with a Rush-pin
C Padiographic and clinical healing after 6 months





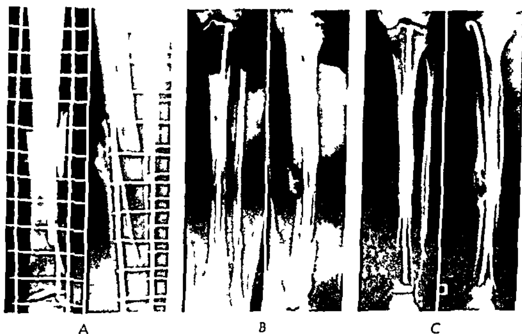
Fig 7 PTB-cast



A B

Fig 4 Longitudinal tibial shaft fracture treated with open reduction and osteosynthesis with screws

Case 26 A Preoperative B Radiographic and clinical healing four months after the operation



A B C

Fig 5 Comminuted transverse fracture of the tibial shaft treated with closed reduction and fixation with a Rush-pin

Case 82 A On admission B In PTB-cast C Radiographic healing after 13 months

A B C

Fig 6 Double fracture of the tibial shaft treated with open reduction and fixation with a Rush pin

Case 93 A On admission B After open reduction and fixation with a Rush-pin
C Radiographic and clinical healing after 6 months

Fig 7 PTB cast



Fig 8 Reaming and Kuntscher-nailing for delayed union of tibial shaft fracture

Case 49 A Transverse fracture at 10 months with visible fracture-line, sclerosis of bone ends and pain on weight-bearing B Radiographic and clinical healing 11 months after the secondary operation

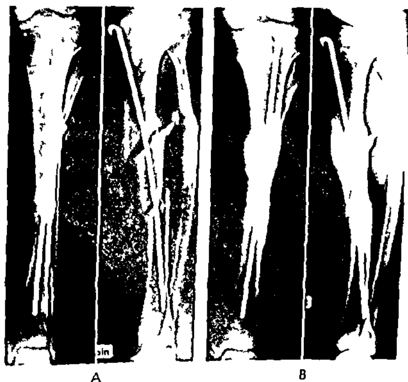


Fig 9 Bone grafting for delayed union of tibial shaft fracture

Case 64 A Double fracture at five months with *instability* and no visible callus formation B Radiographic and clinical healing 9 months after the secondary operation

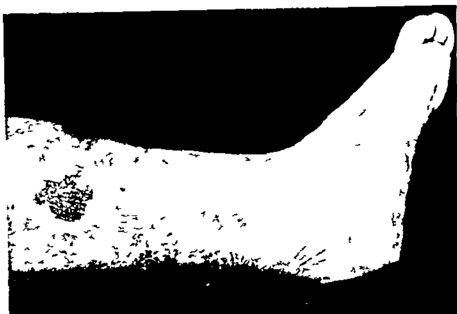


Fig 10 Superficial skin necrosis caused by the PTB-cast

Case 93 The necrosis was probably due to an attempt to correct the fracture angle during the application of the PTB-cast



Fig 11 Loose screws in a longitudinal tibial shaft fracture after weight-bearing in PTB-cast

Case 12 A Immediately after the operation B After 3 weeks of weight-bearing in PTB-cast Continued weight bearing did not cause any further displacement the fracture healed at 12 weeks



Fig 12 Residual deformity after bilateral tibial shaft fractures

Case 46, 47 The angulation was 13° and 15° on the left and right side, respectively



Fig 13 Progression of angulation of tibial shaft fracture

Case 42 A After wedging of cast B After 9 weeks of weight-bearing The difference in angulation was 12°

Allgöwer M. Lecture at the International AO-course in Davos, December 1975

Balkfors B Femårsmaterial av PTB-behandlade tibiadiafysfrakturer En preliminär rapport (Five-year material of PTB-treated tibial shaft fractures A preliminary report) Read at the meeting of the Swedish Orthopaedic Association in Falun 1974

- *Personal communication* 1977

Bauer G C H Edwards P Widmark P H Shaft fractures of the tibia Etiology of poor results in a consecutive series of 173 fractures Acta Chir Scand 124 386 1962

-, Hulth A Kompressionsosteosyntes enligt AO vid underbenets diafysfrakturer bör överges (The AO method for compression osteosynthesis when treating tibial shaft fractures ought to be rejected) Läkartidningen *70* 4752 1973

Bergentz S E Postoperativ tromboembolism Läkartidningen 72 2273 1975

Borelius J Om behandling av frakturer på underbenet (On the treatment of fractures of the leg) Hygiea 56 578 1894

Bowers W H Wilson F C Greene W B Antibiotic prophylaxis in experimental bone infections J Bone Joint Surg 55-A 795 1973

Broström L Eriksson E PT-gips Kongress-Bericht (9 Internationaler Kongress für Ski-Traumatologie und Wintersportmedizin in Garmisch-Partenkirchen) Nebel-Verlag Garmisch-Partenkirchen p 127 1970

Brown P W The early weight bearing treatment of tibial shaft fractures Clin Orthop 105 167 1974

- *Urban J G Early weight-bearing treatment of open fractures of the tibia J Bone Joint* Surg 51-A 59 1969

Burkhalter W E Protzman R The tibial shaft fracture J Trauma 15 785 1975

Charnley J The closed treatment of common fractures Livingstone London Third Edition 1961

Christensen N O *Kuntscher intramedullary reaming and nail fixation for non-union of* fracture of the femur and the tibia J Bone Joint Surg 55-B 312 1973

Dehne E Ambulatory treatment of the fractured tibia Clin Orthop 105 192 1974

Deffer P A Hall R M Brown P W Johnson E V The natural history of the fractured tibia Surg Clin North Am 41 1495 1961

Edwards P Fracture of the shaft of the tibia 492 consecutive cases in adults Importance of soft tissue injury Acta Orthop Scand suppl 76 1965

- Nilsson B E R Graphic representation of healing time in fractures of the shaft of the tibia Acta Orthop Scand 36 104 1965

Ellis H Disabilities after tibial shaft fractures With special reference to Volkmann s ischaemic contracture J Bone *Joint Surg 40-B 190* 1958a

- The speed of healing after fracture of the tibial shaft J Bone *Joint Surg* 40-B 42 1958b



Fig 12 Residual deformity after bilateral tibial shaft fractures

Case 46, 47 The angulation was 13° and 15° on the left and right side, respectively



Fig 13 Progression of angulation of tibial shaft fracture

Case 42 A After wedging of cast B After 9 weeks of weight-bearing The difference in angulation was 12°

Karlström G Olerud S Ipsilateral fracture of the femur and tibia J Bone Joint Surg 59 A 240 1977

Ketenjian A Y Shelton M L Primary internal fixation of open fractures A retrospective study of the use of metallic internal fixation in fre h open fractures J Trauma 12 756 1972

King D M Experience with the below-knee total-contact cast in the management of tibial fractures Aust NZ J Surg 45 54 1975

Lambding C S Simple technique for managing tibial shaft fractures Am Fam Physician 8 178 1973

Langård Ø Bø O Segmental tibial shaft fractures Acta Orthop Scand 47 351 1976

Lidgren L Sandegård J Infektionsförebyggande rutiner vid frakturkirurgi på svenska sjukhus 1975 (Prevention of infection in fracture surgery at Swedish hospitals in 1975) Läkartidningen 74 640 1977

Lindahl O Rigidity of immobilization of oblique fractures Acta Orthop Scand 35 39 1964

van der Linden W Sunzel H Larson K Fractures of the tibial shaft after skiing and other accidents J Bone Joint Surg 57-A 321 1975

Lottes J O Medullary nailing of the tibia with the triflange nail Clin Orthop 105 253 1974

Matsen F A III Clawson D K The deep posterior compartmental yndrome of the leg J Bone Joint Surg 57-A 34 1975

Mayo K A Sheridan G W Krugmire R B Jr Monitoring of intramuscular pressure Surgery 79 702 1976

Merle d Aubigné R Maurer P Zucman J Masse Y Blind intramedullary nailing for tibial fractures Clin Orthop 105 267 1974

Mubarak S J Hargens A R Owen C A Garetto L P Akeson W H The wick catheter technique for measurement of intramuscular pressure A new research and clinical tool J Bone Joint Surg 58 A 1016 1976

Muller M E Allgöwer M Willenegger H Manual of internal fixation Springer-Verlag Berlin Heidelberg New York 1970

Nicoll E A Fractures of the tibial shaft A survey of 705 cases J Bone Joint Surg 46 B 373 1964

Closed and open management of tibial fractures Clin Orthop 105 144 1974

Norberg L Öppen cerclagebehandling av tibiadiafysfrakturer En efterundersökning (Tibial shaft fractures treated with open reduct on and osteosynthesis with encircling wire A follow up study) Dissertation at Göteborg University 1977

Norman O Beskrivande geometri som hjälpmedel vid bestämning av collum- anteversions- och d afysvinkeln samt frakturvinkeln (Descriptive geometry as an aid in the determination of the femoral neck anteversion and diaphysis angles and of fracture angles) Nord Med 73 446 1965

Ernst C B, Kaufer H Fibulectomy-fasciotomy An important adjunct in the management of *lower extremity arterial trauma J Trauma 11 365 1971*

Feagin J A, White A A III Volkmann s ischemia treated by transfibular fasciotomy *Milit Med 138 497 1973*

Fowler P J, Willis R B Vascular compartment syndromes *Can J Surg 18 157 1975*

Gallinaro P, Crova M, Denicolai F Complications in 64 open fractures of the tibia Injury 5 157 1973

Gamble W E, Clayton M L, Leidholt J O, Cletcher J O Complications following treatment of tibial fractures with weight-bearing J Bone Joint Surg 54-A 1343 1972

Gurd F B The ambulatory treatment of fractures of the lower extremity Surg Gynecol Obstet 70 385 1940

Gustilo R B, Anderson J T Prevention of infection in the treatment of one thousand and *twenty-five open fractures of long bones J Bone Joint Surg 58-A 453 1976*

Hansson L I, Hybbinette C-H, Sjöstrand L-O Reimplantation of a traumatically expelled tibial diaphysis Acta Orthop Scand 48 108 1977

Harvey F J, Hodgkinson A H T, Harvey P M Intramedullary nailing in the treatment of open fractures of the tibia and fibula J Bone Joint Surg 57-A 909 1975

Hjelmstedt A, Bergvall U Incidence of thrombosis in patients with tibial fractures A phlebographic study Acta Chir Scand 134 209 1968

Hoaglund F T, States J D Factors influencing the rate of healing in tibial shaft fractures Surg Gynecol Obstet 124 71 1967

Holden C E A Compartmental syndromes following trauma Clin Orthop 113 95 1975

Höjer H, Gillquist J, Liljedahl S-O Combined fractures of the femoral and tibial shafts in the same limb Injury 8 206 1977

Infanger K, Fenner A, Cadalbert M, Schauman M Ergebnisse der operativen Behandlung der Unterschenkelschaftfrakturen anhand von 230 Fällen Helv Chir Acta 3 311 1971

Jensen J S, Hansen W H, Johansen J Tibial shaft fractures A comparison of conservative treatment and internal fixation with conventional plates or AO compression plates Acta Orthop Scand 48 204 1977

Karaharju E O Alho A, Nieminen J The results of operative and non-operative management of tibial fractures Injury 7 47 1975

Karlström G *Studies on the operative treatment of tibial shaft fractures* Dissertation at Uppsala University 1976 Acta Universitatis Upsaliensis 236 1976

-, Lönnerholm T *Olerud S Cavus deformity of the foot after fracture of the tibial shaft* J Bone Joint Surg 57-A 893 1975

-, Olerud S Fractures of the *tibial shaft* A critical evaluation of treatment alternatives Clin Orthop 105 82 1974

-,- Percutaneous pin *fixation of open tibial fractures* J Bone Joint Surg 57-A 915 1975

Karlström G Olerud S Ipsilateral fracture of the femur and tibia J Bone Joint Surg 59-A 240 1977

Keten ian A Y, Shelton M L Primary internal fixation of open fractures A retrospective study of the use of metallic internal fixation in fresh open fractures J Trauma 12 756 1972

King D M Experience with the below-knee total-contact cast in the management of tibial fractures Aust NZ J Surg 45 54 1975

Lambding C S Simple technique for managing tibial shaft fractures Am Fam Physician 8 178 1973

Langård Ø Bø O Segmental tibial shaft fractures Acta Orthop Scand 47 351 1976

Lidgren L Sandegård J Infektionsförebyggande rutiner vid frakturkirurgi på svenska sjukhus 1975 (Prevention of infection in fracture surgery at Swedish hospitals in 1975) Lakartidningen 74 640 1977

Lindahl O Rigidity of immobilization of oblique fractures Acta Orthop Scand 35 39 1964

von der Linden W Sunzel H Larsson K Fractures of the tibial shaft after skiing and other accidents J Bone Joint Surg 57-A 321 1975

Lottes J O Medullary nailing of the tibia with the triflange nail Clin Orthop 105 253 1974

Matsen F A III Clawson D K The deep posterior compartmental syndrome of the leg J Bone Joint Surg 57-A 34 1975

Mayo K A Sheridan G W Krugmire R B Jr Monitoring of intramuscular pressure Surgery 79 702 1976

Merle d Aubigné R Maurer P Zucman J Masse Y Blind intramedullary nailing for tibial fractures Clin Orthop 105 267 1974

Mubarak S J Hargens A R Owen C A Garetto L P Akeson W H The wick catheter technique for measurement of intramuscular pressure A new research and clinical tool J Bone Joint Surg 58 A 1016 1976

Muller M E Allgöwer M Willenegger H Manual of internal fixation Springer-Verlag Berlin Heidelberg New York 1970

Nicoll E A Fractures of the tibial shaft A survey of 705 cases J Bone Joint Surg 46 B 373 1964

Clo ed and open management of tibial fractures Clin Orthop 105 144 1974

Norberg L Öppen cerclagebehandling av tibiadiafysfrakturer En efterundersökning (Tibial shaft fractures treated with open reduction and osteosynthesis with encircling wire A follow up study) Dissertation at Göteborg University 1977

Norman O Beskrivande geometri som hjälpmedel vid bestämning av collum- anteversions- och diafysvinkeln samt frakturvinkeln (Descriptive geometry as an aid in the determination of the femoral neck anteversion and diaphysis angles and of fracture angles) Nord Med 73 446 1965

Nylander G, Semb H Veins of the lower part of the leg after tibial fractures Surg Gynecol Obstet 134 974 1972

Olerud S Treatment of fractures by the Vidal-Adrey method Acta Orthop Scand 44 516 1973

–, Karlström G Tibial fractures treated by AO compression osteosynthesis Experience from a five year material Acta Orthop Scand Suppl 140 1972a

–,– Secondary intramedullary nailing of tibial fractures J Bone Joint Surg 54-A 1419 1972b

Owen R, Tsimboukis B Ischaemia complicating closed tibial and fibular shaft fractures J Bone Joint Surg 49-B 268 1967

Patman R D, Thompson J E, Persson A V Use and technic of fasciotomy as an adjunct to limb salvage South Med J 66 1108 1973

Patzakis M J, Harvey J P, Ivler D The role of antibiotics in the management of open fractures J Bone Joint Surg 56-A 532 1974

Phemister D B Treatment of ununited fractures by onlay bone grafts without screw or tie fixation and without breaking down of the fibrous union J Bone Joint Surg 29 946 1947

Rittman W W, Matter P, Allgöwer M Behandlung offener Frakturen und Infekthäufigkeit Acta Chir Austr 2 18 1970

Rorabeck C H, MacNab I Anterior tibial-compartment syndrome complicating fractures of the shaft of the tibia J Bone Joint Surg 58-A 549 1976

Rosentahl R E, MacPhail J A, Ortiz J E Non-union in open tibial fractures Analysis of reasons for failure of treatment J Bone Joint Surg 59-A 244 1977

Rush L V Atlas of Rush pin technics The Beverion Company, Meridian, Mississippi 1955

Ruedi Th, Kolbow H Allgöwer M Erfahrungen mit der dynamischen Kompressionsplatte (DCP) bei 418 frischen Unterschenkelschaftbruchen Arch Orthop Unfall-Chir 82 247 1975

Sarmiento A A functional below-the-knee cast for tibial fractures J Bone Joint Surg 49-A 855 1967

– A functional below-the-knee brace for tibial fractures A report on its use in one hundred thirty-five cases J Bone Joint Surg 52-A 295 1970

– Functional bracing of tibial fractures Clin Orthop 105 202 1974

Seddon H J Volkmann s ischaemia in the lower limb J Bone Joint Surg 48-B 627 1966

Sheridan G W, Matsen F A III Fasciotomy in the treatment of the acute compartment syndrome J Bone Joint Surg 58-A 112 1976

Smith J E M Results of early and delayed internal fixation for tibial shaft fractures J Bone Joint Surg 56-B 469 1974

Solheim K Tibial fractures treated according to the AO method Injury 4 213 1973

Sumon R K The management of tibial shaft fractures by early weight bearing in a patella tendon bearing cast A comparative study J Trauma 17 97 1977

Sundén G Wiberg G Volkmann s ischemiska kontraktur i nedre extremiteten Läkartidningen 68 3018 1971

Thunold J Varhaug J E Bjerkeset T Tibial shaft fractures treated by rigid internal fixation The early results in a 4-year eries Injury 7 125 1975

Whitesides T E, Haney T C Morimoto K Harada H Tissue pressure measurements as a determinant for the need of fasciotomy Clin Orthop 113 43 1975

Wiedmer U Bianchini D Zur funktionellen konservativen Behandlung der Unterschenkelschaftfrakturen Helv Chir Acta 42 463 1975

Willhoite D R, Moll J H Early recognition and treatment of impending Volkmann s ischaemia in the lower extremity Arch Surg 100 11 1970

Vogl J Czembirek H Jungbluth K H Tiefe Venenthrombosen nach Kompressionsosteosynthesen der Tibia Klinisch phlebographische Stude an 73 Patienten Chirurg 43 459 1972

Volkmann R Die ischämischen Muskellahmungen und -Kontrakturen Centralblatt fur Chirurgie 8 801 1881

Wyman E T Jr Barr J S Jr Fractures of the tibia and fibula In Trauma management Ed by Edwin F Cave John F Burke and Robert J Boyd Year Book Medical Publishers Inc Chicago p 793 1974

Zucman J Maurer P Two-level fractures of the tibia Results in thirty-six cases treated by blind nailing J Bone Joint Surg 51-B 686 1969

- Primary medullary nailing of the tibia for fracture of the shaft in adults Injury 2 84 1970

X CODED DATA

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	72	53F	10			2		a		13	4		1(a)				7	19	2	15	6	a
	73	17M	2			1					1		1( )				7	28	2	16	5	b

A	B	C	D	E	F	G	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X
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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X
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Fra t res e 1 d 3 f o the so ce ma e ia) (G o ps 3 pa, B)

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1	111	78F	10			2				24	4									35	P	
	112	53M	10			3					6									18	P	
	113	31M	10			3				8	3			2	7		3	144	3	52		b
4	114 (125)	74M	2			2					2					7 9	146			10	P	b
	115	8 4	1			2					10 4			1	7		23	69	3		P	c
	116	25M	2			2				24	4	1		1		1	63	88	2			b
	117	79M	5			2				72	10 4					2 35 7	116			19	P	
	118	75K	10			1					1			3			79			12	P	a
	119	15M	2			2					1	1				35	49			13	S	a
	120	27M	7								4					9	85	80	1	17		a
	(121)	27M	7			1				3	9 10	1 4 5			3		85	1				d
	122	58F	1								10 4	1 1			2	1 8 9	1 0	88	7	4		
5	123	18M	2			2				7	5	2	1			1 8	31	46	2	17		a
	124	16M	2			2		d		b	5		1( )			35 9	44	4	1	15		a
	125 (114)	74M	2					b			4 9	4	1(1				146			13	P	d
	126	18F						b			1	1	1(a)				1		1	19	S	
	127	17M	4			2		b			10 1		1(d)			1 3	11			5		
	128	15M	2			3		b		4	2		1(1				4					a

Ca e 124 has bee p bl hed by 1 n t 1 (1977)

XI KEY TO DATA

[illegible] fracture

Displaced longitudinal closed

Displaced longitudinal open

Non-displaced longitudinal [illegible]

Displaced transverse closed

3 Displaced transverse open

Non-displaced transverse [illegible]

Non-displaced transverse [illegible]

Non-displaced longitudinal closed

Case

[illegible] fractures represent patients on [illegible] lateral fractures

Age and sex

[illegible]

Car [illegible] passenger injured [illegible] accident

Fall [illegible] height [illegible]

Blow from heavy object [illegible] crush injury

Severe [illegible] displacement on [illegible]

[illegible] fracture

Double fracture

Primary and secondary treatment of wound

[illegible]

5. Secondary treatment

Secondary treatment of fracture

[illegible] grafting

Complications

Necrosis of [illegible]

Necrosis from pressure [illegible] the plaster

[illegible]

Peroneal palsy

Thrombosis

6. Pulmonary embolism

Delayed union

Other fractures [illegible]

[illegible] fracture of the pelvis

[illegible] fracture the neck [illegible] the femur

Fracture [illegible] shaft [illegible] the femur

Fracture [illegible] the scapula

Fracture [illegible] the humerus

Fracture of the [illegible]

Head injury

Rupture [illegible] the spleen

Other [illegible]

Other [illegible]

Days [illegible] hospital [illegible]

[illegible] studying

Excellent

Good

Acceptable

Poor

Not evaluable for [illegible]

Impossible to evaluate because [illegible] other injury or disease



Marianne Bergquist Ullman and Ulf Larsson

Acute Low Back Pain in Industry

A controlled prospective study with special reference to therapy and confounding factors

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Acute Low Back Pain in Industry

A controlled prospective study with special reference to therapy and confounding factors

BY

MARIANNE BERGQUIST ULLMAN AND ULF LARSSON

MUNKSGAARD COPENHAGEN 1977

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AIMS OF THE STUDY

The aims of this investigation were

1 to describe a population of patients with acute and subacute low back pain,

2 to determine whether certain confounding factors irrespective of treatment given, are of any prognostic value when assessing the course of acute and subacute low back pain,

3 to evaluate the effect of three modes of therapy on acute and subacute low back pain

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ABBREVIATIONS

MMPI = Minnesota Multiphasic Personality Inventory
Hs = Hysteria
Hy = Hypochondriasis
SLR = Straight Leg Raising Test
NHIO = National Health Insurance Office

INTRODUCTION

GENERAL ASPECTS

Incidence and economical aspects

The importance of back pain syndromes is due to their high prevalence in the community and their effect on the individual in terms of pain and disability To obtain a diversified picture of the magnitude of the problem several factors must be considered including the frequency in the population, the variations in the course the age distribution the number of patients with serious disability and inability to work and the economic consequences Evaluation of the epidemiology of low back pain is hampered by incomplete statistics and a lack of uniform definitions

Probably up to 80 % of all people will experience back pain to some extent during their active life (Hult 1954 Horal 1969 Nachemson 1976) In most cases the condition is self limiting with recovery within one month in 70 % and within two or three months in 90 % while about 4 % seem to have a duration exceeding six months (Horal 1969) Recurrences are frequent and three or more episodes have been reported in 30 – 70 % of the afflicted patients (Hult 1954 Horal 1969) Although the course is usually benign the number of severely disabled people is considerable owing to the general occurrence of the ailment The back pain patients with more than six months incapacity to work have been found to be comparable in number with those unfit for work due to rheumatoid arthritis and heart trouble (Haber 1971) And it has been reported that of those off work because of back pain for longer than six months only 50 % will ultimately return to work (McGill 1968) Back pain is most common between the ages of 30 and 55 years (Hult 1954 Horal 1969 Hirsch et al 1969 Kelsey 1975) Although the long term disability is most pronounced in the older age groups (Haber 1971 Wood & McLeish 1974) it is clear that back pain usually affects man in

his most productive age Hence, back pain occupies a prominent position in the statistics on sick leave, accounting for 10 – 15 % of all lost work days in Sweden (Helander 1973) Among manual workers in England the annual absence from work because of back pain is calculated to be about 70 weeks per 100 men employed (Anderson J A D , 1976)

The economic consequences are based on the fact that 1 % of all work-days are believed to be lost due to back pain (Helander 1973) To this cost the expenses of treatment must be added In England (Wood 1976), in a population of 1 000 persons about 20 each year will consult their general practioner, scarcely 10 will be referred to an orthopaedic clinic, and a little less than one will be admitted to hospital on account of back pain

Etiology and classifications of low back pain

Back pain is a clinical manifestation that can be caused by a variety of known diseases and morphological changes The herniated disc is thought to account for 5 % of all cases (Hirsch 1966) Back pain is occasionally caused by infection, tumours, fractures, osteoporosis, ankylosing spondy litis, rheumatoid arthritis spinal stenosis and intraabdominal or intra pelvic disease Certain radiological abnormalities with a definite or ques tionable association with back pain are summarized in Table 1 where some changes not related to back pain are also listed (Nachemson 1976) The majority of back pain patients do not fall into any of the above mentioned categories, and as a rule back pain is a complaint where the underlying pathophysiology is unfortunately unknown Almost every anatomical structure in the motion segment of the spine has been the subject of etiological discussions (Nachemson 1960 Horal 1969)

Morphological changes occur most frequently in the intervertebral disc (Friberg & Hirsch 1949 Nachemson 1971 Jayson & Barks 1973 Roth man 1973), and also in the intervertebral joints (Badgley 1941 Lewin 1964), and in the vertebral body (Vernon Robert & Pirie 1973 Rolan der & Blair 1975) The degenerative changes in the intervertebral joints of the lumbar spine, however, appear relatively late in life (Hirsch 1966 Nachemson 1976) For several decades attention has mainly been direct ed to the intervertebral disc There is a lack of conclusive evidence but a

Table 1 Radiological abnormalities in the lumbar spine that are of significance for low back pain.

Irrelevant	Single disc narrowing and spondylosis
	Facet arthrosis, subluxation and tropism
	Disc calcification
	Lumbarization sacralization
	Intraspongy disc herniation (Schmorl)
	Spina bifida occulta
	Accessory ossicles
	Mild to moderate scoliosis
Questionable	Spondylolysis
	Rethrolisthesis
	Severe lumbar scoliosis ($>80^\circ$)
	Severe lordosis
Definite	Spondylolisthesis
	Lumbar osteochondrosis (Scheuerman)
	Congenital/traumatic kyphosis
	Osteoporosis
	Marked multiple disc narrowing

(After Nachemson The Lumbar Spine – An Orthopaedic Challenge Spine 1 59 1976)

number of indirect indications of a central role of the disc in the etiology of most cases of low back pain (Nachemson 1971) Disc degeneration is a more or less physiological aging phenomenon but it is assured that certain not yet clearly defined stages in the process are of significance for the production of pain syndromes (Nachemson 1971)

The degeneration of the disc includes morphological changes as well as alterations in the content of water collagen mucopolysacharides and cells (Friberg & Hirsch 1949, Nachemson 1971 Jayson & Barks 1973, Rothman 1973 Naylor & Shentall 1976 Naylor 1976) The nutrition to

the degenerated disc is by diffusion only and the central parts, especially the boundary zone between the pulpy nucleus and annulus fibrosus pos-teriorly, are at risk for nutrient defiency (Nachemson et al. 1970, Ma-roudas et al. 1975, Nachemson 1976). The posterior area of the annulus fibrosus is early and frequently the site of radiating ruptures (Friberg & Hirsch 1949, Nachemson 1971, Jayson & Barks 1973), which might fa-cilitate leakage of chemically irritant products and allow them to come into contact with nerve endings (Nachemson 1971). Disc degeneration with herniation has also been found to be accompanied by auto-immu-nological phenomena (Bobechko & Hirsch 1965, Gertzbein et al. 1975, Bisla et al. 1976).

Information on the mechanical properties of the spine is available from measures of intradiscal pressure (Nachemson 1960, Nachemson & Morris 1964, Nachemson & Elfstrom 1970, Nachemson 1976). These studies show that the pulpy nucleus acts hydrostatically, and the whole disc functions as a shock absorber. In the back patient increased mechanical load invariably increases the pain. Those positions that are known to be painful in connection with low back pain, e.g. stooping and sitting with-out support, give the highest intradiscal pressures. It has also been shown that the tensile stresses in the posterior part of the annulus can exceed the calculated strength of these fibres during e.g. a lifting manoeuvre, re-sulting in ruptures (Galante 1967, Nachemson 1976).

Whether these ruptures in the annulus fibrosus can cause pain is uncer-tain, but it is an interesting fact that at least 50 % of all attacks of low back pain are reported to start in connection with a minor accident or strenuous movement (Seager 1959, Glover 1960). This finding is also notable considering the occurrence of fractures in the end plate of the disc and subchondral microfractures in the vertebral bodies, which have been demonstrated in recent years (Vernon Robert & Pirie 1973, Ro-lander & Blair 1975, Hansson 1977). Whether these events in the verte-bral bodies are of any clinical importance is not known. The role of the increased intraosseous pressure in vertebral bodies in the pain mechanism is also uncertain (Arnoldi 1972).

Since the etiology is not known in most cases of low back pain, the clas-sification of the disease must be based upon symptoms and clinical find-ings. Unfortunately, there is a lack of general agreement as to definitions and the basic terminology.

The terminology that has been used in this study corresponds to a classification that has recently been presented to the International Society for the Study of the Lumbar Spine (Nachemson & Andersson 1975) This system relates the terminology to symptoms and clinical findings. The duration and the onset of the disease is given as a prefix In paranthesis after the symptom diagnosis additional information can be given e g. x ray findings.

The whole system of classification and the terminology is outlined in Table 2

METHODS OF PHYSICAL THERAPY

A great variety of non-operative treatment methods is used in patients with low back disorders The reason for this is uncertainty about which method to prefer probably owing to the lack of knowledge regarding the structural changes causing the symptoms

There are only a few controlled studies reported in the literature in which the effect of different treatment methods has been investigated.

Manipulation has been evaluated in two separate controlled studies (Glover et al. 1974 Doran & Newell 1975)

Both show an immediate slight superiority of manipulation as compared to conventional physiotherapy orthopaedic corsets and analgesic treatment alone These differences in results disappear after one to three weeks None of the treatments was found to be better than no treatment at all in the long-term perspective There are few statistically valid trials on different forms of traction. Lidstrom and Zachrisson (1970) demonstrated an improvement in most patients with low back pain and sciatica, following Tru Trac traction and isometrical exercises compared to active mobilization of the spine with back muscle strengthening. Lind (1974) on the other hand noted a deterioration among patients with the same diagnosis treated according to the same method Auto-traction was demonstrated in the same study to be significantly superior to bed rest and combined physiotherapy

Table 2 Classification of Low Back Pain (After Alf Nachemson and Gunnar Andersson Classification of Low Back Pain presented to the International Society for the Study of the Lumbar Spine 1975)

TABLE 1 a

PREFIX

Acute 0 – 2 months duration

Chronic More than 2 months duration

Recurring Symptoms recurring after an interval of no symptoms

TABLE 1 b

SYMPTOM DIAGNOSIS

Insufficientia dorsi

Tiredness and light ache or pain provoked by repeated or forceful movements or by some other mechanical stress e g work position or the same work position for a long period of time The troubles are localized to the lumbar region The back feels stiff or weak and the patient tries to avoid certain types of stress which he knows will give this feeling of unease

Lumbago

Ache and pain localized to the lumbar region with an eventual radiation over the gluteal region the hips or the lower part of the abdomen This syndrome is aggravated in the acute stages by all movements and loads, in the more chronic stages only by certain movements and loads on the lumbar spine Mostly the patient needs some type of analgesic The syndrome can set in suddenly or the onset may be over a shorter time period

Sciatica

Ache and radiating pain in one or both lower extremities This is aggravated in the acute stages by all movements and loads to the lumbar spine in the more chronically ill only by certain movements and loads In most instances the patient needs analgesics. The symptoms can be either acute or set in over a shorter time period The clinical picture includes numbness paresthesia and a feeling of weakness in one or both lower extremities.

Rhizopathy

This is a special form of lumbago sciatica or sciatica characterized by the fact that the radiation of the symptoms in the leg is according to the segmental innervation Most often the patient has neurologic signs according to the affected segment.

Lumbago sciatica

Symptoms as in both lumbago and sciatica. One of these can dominate the picture

TABLE 1 c

CLINICAL FINDINGS

Insufficientia dorsi

More rarely pain on palpation in the lumbar spine occurs There is no increased muscular tension There is no increased pain on motion of the lumbar spine No neurologic symptoms Straight Leg Raising Test will not give pain in the lumbar spine

Lumbago

Acute Pain on palpation in the back and/or pelvic region Increased tonus in the lumbar muscles. Definite loss of motion and pain by examination of the motion pattern No neurologic symptoms. Straight Leg Raising Test might be positive Straining coughing sneezing and similar activities give rise to pain in the back

Chronic Eventual pain on palpation in the lumbar spine and limitation of motion No neurologic symptoms. Straight Leg Raising Test can be positive

Sciatica

Pain on palpation can occur in the lumbar region and/or the leg No increased tonus in the lumbar musculature There is limitation of motion in the lumbar spine and also sometimes in the hip joint Straight Leg Raising Test positive Neurological symptoms occur in rhizopathy (see below).

Rhizopathy

Clinical findings as in sciatica or lumbago sciatica Straight Leg Raising Test nearly always positive Neurological symptoms commonly positive Straining coughing sneezing and similar activities give rise to pain in the engaged radicular segment

Lumbago sciatica

Clinical findings as in lumbago and sciatica Either of these can be dominant

TABLE 1 d

PARENTHETIC INFORMATION

Radiologic diagnosis
Trauma
Psychiatric psychological or social diagnosis
Pathoanatomically defined diseases of the back (e g. spondylitis pelvospondylitis ossificans etc)
Tumours

Investigations on the curative and preventive effect of strengthening dynamic back exercises (White 1966 Kendall & Jenkins 1968 Lidstrom & Zachrisson 1970) have given discouraging results. These studies have rather supported recommendations of immobilization of the spine for relief of symptoms (White 1969)

None of the above mentioned studies provides the answer to the search for an effective inexpensive and simple remedy for low back disorders.

In an effort to rationalize the therapy towards these goals, a ' Back School was introduced by Lidstrom & Zachrisson (1973) based on biomechanical and epidemiological studies on low back disorders This method of treatment is described in detail on page 29 – 31

VOCATIONAL FACTORS

At present there is not enough evidence to confirm an etiologic relationship between low back disorders and mechanical strain on the back Consequently the true relationship between the effect of specific strain on the low back and subsequent clinical manifestations has not been established

It is widely recognized however that an increased load on the already afflicted back produces more pain (Hult 1954 Rowe 1969 Nachemson 1971 Chaffin 1973, Magora 1974)

Measurements of the intradiscal pressure in various postures (Nachemson 1970 Andersson 1974) have shown a similar load on the lumbar spine while standing in a stooped position of 20° as in sitting without support.

These results may be of importance when explaining the outcome of certain studies (Hult 1954, Rowe 1969) on the frequency of low back pain among employees in industry These investigations indicate that there is no significant difference in the occurrence of low back pain among office employees compared to manual workers. In other studies a significantly higher incidence of back pain is demonstrated among heavy industry workers than among people with less strenuous occupations (Lawrence 1955 Ikata 1965 White 1966 Rowe 1969 Magora 1970 Chaffin 1974).

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Clinical findings as in lumbago and sciatica Either of these can be dominant

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PARENTHETIC INFORMATION

Radiologic diagnosis

Trauma

Psychiatric psychological or social diagnosis

Pathoanatomically defined diseases of the back (e g. spondylitis pelvospondylitis ossificans etc)

Tumours

The discrepancies that seem to be present between the results presented in the above mentioned investigations may be explained by the various methods of approaching and assessing the same problem The factors observed to contribute to a high incidence or triggering of low back pain are summarized and listed in Table 3

Table 3 Factors contributing to the incidence or triggering of low back pain.

Incidence	Triggers
Heavy industry work	Weight lifting
Frequent / Occasional lifting	Bending
Excessive / Accidental bending	Rotation
Sudden maximal efforts	
Prolonged postures	
Forceful movements	

The occupational environment is in this study treated as a confounding variable the influence of which is analysed with reference to prognosis among people with acute and subacute low back pain

PSYCHOLOGICAL FACTORS

In recent literature the distribution of psychological traits in populations of back pain patients is studied usually without etiological implications. Westrin (1970) found significant differences regarding several personality traits in a comparison between patients who had been sicklisted for back pain and their matched controls. Psychiatric problems, however, were not more frequent among the back patients, except for cerebrolesional symptoms. In another epidemiological study Nagi et al. (1973) were able to relate certain indices of emotional and psychological problems to the occurrence of back pain

Other investigations have yielded further information on the incidence of back pain in specific operations of work (Hult 1954, Ikata 1965, Chaffin 1973) A considerably high incidence of back disorders was disclosed in tasks involving very frequent strenuous lifting A high incidence was also observed in occupations involving only occasional lifting.

A moderate amount of daily lifting was not found to influence the rate of backache This finding was supported by the results obtained by Magora (1972) who found no relation between lifting and increased incidence of low back pain Similarly, no evidence was found of an association between the occurrence of acute disc herniation and exposure to lifting, demonstrated in a recent case control study by Kelsey (1975)

Weight lifting is also mentioned to be one of the most common triggers of low back pain Magora (1974) related the subjective assessment of the cause to back pain and the occupation Weight lifting in combination with bending was mentioned to be a very common cause A combination of flexion, rotation and lifting was found to be the most common cause of back injuries at work according to Troup et al (1970)

Other physical operations such as bending, rotation, reaching and sudden maximal efforts are also thought to be connected with a high frequency of back pain (Lawrence 1955, Magora 1973) In accordance with the previous analysis of frequent and rare lifting respectively (Chaffin 1973) only excessive bending or occasional ante-flexions during the day increased the number of back cases (Magora 1973)

Sedentary occupations have also been subjected to attention in a few studies A sedentary occupation, performed for several years, was found to be a significant predisposing factor for acute disc herniation (Kelsey 1975) Similar findings were demonstrated by Kelsey (1975) when studying the association between the driving of motor vehicles and acute disc herniation These observations support previous implications by Magora (1972), in which a higher incidence of back ailments was found in occupations with prolonged sitting (more than four hours daily) Magora (1972) found a similar high rate in occupations involving almost no sitting but mainly standing These results indicate that an occupation allowing a proper amount of variation of postures is preferable to a repetitive work as regards the postures.

groups one with extremity injuries and one with back pain. The patients were classified according to physical and psychological ratings. The latter included several inventories among them the MMPI. Of the two ratings the psychological one correlated much more strongly to return to work in the back pain group but not in the extremity injured group. Wifling et al. (1973) tested patients psychologically before spinal fusion was performed. The MMPI discriminated with significance between success and failure the neurotic triad being found in the failure group. Forrest and Wolkind (1974) described 50 non-operatively treated back patients. They were able to predict the outcome of their treatment using a self rating scale of psychoneurotic symptoms and behaviour, the Middlesex Hospital Questionnaire. Wiltse and Rocchio (1975) used the MMPI the Cornell Medical Index and an intelligence test the Quick test, together with physicians ratings and biographical data, as predictors of success of chymopapain injection therapy in 130 patients. The MMPI Hs- and Hy-scales were found to be of value. In fact there was a 90 % chance of a good result with very low scores on these scales, but only a 10 % chance when the scores were very high. There were no clinical differences between the high-score and low score groups. The second best predictor was the physician s own opinion of the patient's psychogenic status. White et al. (1973) found no significant differences in the results of cervical spine fusions in patients with normal and abnormal scores in a psychological inventory the Cornell Index. An association between back pain and certain psychological traits seems clear on the basis of the reported studies. Some of the studies indicate that populations with and without strong association to these factors have different prognoses. The essential mechanism for this association is obscure however and there is a lack of information about the distribution of psychological traits prior to the onset of back pain. Most of the reported studies deal only with chronic cases. It would be of interest, therefore, to study the distribution of the psychological traits and their potential predictive capacity in acute cases

SOCIAL FACTORS

The literature on back pain in relation to social factors other than purely vocational ones is limited. It is often difficult to define and measure abnormalities in these areas.

The psychological conditions associated with back pain are often evaluated using personality inventories, most frequently the MMPI (Minnesota Multiphasic Personality Inventory) The results in groups of chronic back pain patients are uniform in different studies The hysteria (Hs), hypochondriasis (Hy) and depression (D) scales are elevated, while the other scales are normal or only slightly raised (Hanvik 1950, Beals & Hickman 1972 Sternbach et al 1973, Timmermans & Sternbach 1974 Wilfling et al 1973, Gentry et al 1974, Wiltse & Rocchio 1975) The Hs , Hy and D scales are often referred to as the neurotic triad Not infrequently they form a specific pattern in the MMPI answer sheet, named the "conversion V", with significant rise of Hs and Hy and a slight rise of D There is some confusion in the literature about the stability of these scales in low back pain over a period of time (Phillips 1964, Beals & Hickman 1972, Gentry et al 1974, Wiltse & Rocchio 1975) Sternbach & Timmermans (1975) have shown that the raised neurotic triad has a tendency to become normal after successful rehabilitation The close connection between the experience of back pain and some of the scales in the MMPI is also obvious from the investigations by Ranford et al. (1976) They classified patients with chronic back pain according to their scores on the Hs and Hy scales A strong correlation was found between a high value on these scales and a tendency to give an anatomical and "expanded' description of their complaints as visualized in pain drawings Freeman et al (1976) were able to distinguish between three groups of back pain patients an organic, a functional and a mixed group The three groups differed significantly on several of the scales of the MMPI test

In a few studies back pain patients have been compared to other groups of patients with regard to psychological factors. Phillips (1964) found that both fracture patients and a group of back patients had higher values on the Hs , Hy and D scales than a group of 'normals" but that the differences were more pronounced in the back pain group Similar findings have been reported by Beals et al. (1972) Sternbach et al (1973) compared patients with chronic back pain with a number of patients with rheumatoid arthritis in Steinbrocker s anatomical and functional class II–III The back pain patients were more depressed and more often adopted an invalid s self concept and life style

In several investigations the predictive values of psychological factors have been studied in connection with different treatment regimens for back pain Beals et al. (1972) followed the course of 180 patients in two

The company has its own health-centre divided into a Medical Division, an Industrial Safety Division and a Social Welfare Division. The Medical Division has seven physicians, two physiotherapists and a number of nurses. The health service is directed towards preventive medicine and work related disorders. There is an emergency department to which patients with acute back pain may come for consultation. The investigation was carried out in the health centre by a physiotherapist and an orthopaedic surgeon from the Department of Orthopaedic Surgery I Sahlgren Hospital with the assistance of the staff at the centre

PATIENTS

Criteria for admission to the trial

To be admitted to the trial the patients with low back pain had to meet the following criteria

1. Acute or subacute back pain localized to the lumbosacral region with or without radiation to the thigh
2. Duration of pain before entry to the trial not longer than three months.
3. A pain free year before the onset of the current episode

The criteria for excluding patients were as follows

1. Chronic pain
2. Rhizopathy
3. Pregnancy
4. Back surgery
5. Spondylolisthesis
6. Infections
7. Tumours
8. Ankylosing spondylitis
9. Fractures
10. Senile osteoporosis
11. Structural scoliosis

217 patients were admitted to the trial. All patients were reassessed during the year following the initial examination

In a few Scandinavian socio medical investigations on back pain a high incidence of multivarious social problems has been found (Westrin 1970, Natvig 1970, Helander 1973) For example, there is an association be tween sick leave for back pain and abuse of alcohol (Lokander 1962, He lander 1973) A high percentage of broken marriages, family problems and financial difficulties has been noted among back patients (Natvig 1970 Westrin 1970) Several authors consider that back pain is associ ated with a low educational level (Natvig 1970, Westrin 1971, Nagi 1973, Gentry et al 1974) but there is no general agreement on this (Magora 1970), and the association might be caused by a difference in the occu pational situation of the less well educated patients

Roslund (1974) found psychological or social problems in almost half of a population of multi operated back patients He was also able to estab- lish that the prognosis in backsurgery was directly dependent on the presence of psychosocial complications

The investigations quoted point to a link between back disorders and social problems There is, however, a high proportion of chronic cases and individuals with longstanding sick leave in the reported studies The social conditions represent external circumstances that most probably will be affected by chronic disability and inability to work There is a lack of information as to whether a similar association exists in early acute, cases and to what degree the occurrence of social problems influ ences the prognosis in these cases

PROJECT DESIGN

GEOGRAPHICAL LOCATION

This trial was carried out at the Automotive Division of AB Volvo Go teborg Sweden There are 13 000 people working in the site of the com pany where this trial was performed 8 500 are manual workers and 4 500 are clerks and executives The workshops at the plant are mainly engaged in light industrial work with a predominance of assembly line work Most parts of the cars are transported to the Göteborg division from other Volvo factories Hence, there is also a good deal of materials handling at the factory in Goteborg

Questionnaire on vocational factors

This form included questions on the category of employment (office or manual work) the occurrence of shift work and an assessment of the physical and mental load on the patient in his work using questions that have previously been used by Magora (1972 1973) The questions included an analysis of the patients working posture (sitting standing fixed) and an evaluation of the need for bending, twisting lifting and forceful movements during the patient s work The need of concentration and the degree of variation during work and possibilities of taking breaks were registered as well as the patient s feelings of fatique and nervousness during work The patient was also asked about his satisfaction with his work and whether he would like to change jobs The questions asked have three alternative answers listed in Table 4

Questionnaire on socio medical factors

The form listed questions on family conditions (marriage children and housing participation in sports activities (yes, no) and physical exercise (>once/week not regularly rarely) and the presence of previous or current psychosomatic symptoms (gastric ulcer gastritis headaches chest pain)

Forms for the registration of symptoms

Initial assessment

The history of back pain was summarized and the duration of the current episode was recorded The circumstances of the onset of symptoms were also noted The intensity and quality of pain and the degree of functional limitation were analysed in the following way

A Pain intensity

PROCEDURE

Screening assessment

Patients consulting the health centre because of low back pain were assessed and screened by the physiotherapist according to the criteria for admission to the trial The patients admitted were at the same time informed about the purpose of the investigation and asked whether they were willing to participate in the trial They were then asked to fill in a psychological test form and a questionnaire regarding their working conditions described in detail on page 23 and Table 4 They were also examined by the orthopaedic surgeon

Initial assessment

Standardized assessment forms for onset related factors, the intensity of pain, functional limitation, and objective clinical findings were utilized by the physician when examining each patient After being assessed, the patients were allocated at random to one of the three treatments (See statistical methods page 39) The orthopaedic surgeon was in no way involved in any of the treatments given to the patients

Reassessment

After the initial examination the patients were reassessed after ten days three weeks, six weeks three months six months and one year On these occasions the same assessment forms were used as when examining the patients initially A few additional questions concerning changes in the clinical picture were, however, added This standardized procedure for interviewing the patients ensured that each patient received an identical examination If any patient recovered before the ten day reassessment the three week re-examination was excluded Similarly, the six week examination was left out if the patient recuperated after the three week examination This means that the patients were reassessed at least five times and at the most seven times during one year

The patients were asked to choose one of the following descriptions of their pain

1 Terrible pain
2 Intense pain
3 Sharp stabbing pain
4 Spasmodic pain
5 Intense dull aching
6 Slight stabbing pain
7 Slight dull aching
8 Feeling of discomfort
9 Feeling of stiffness
10 Feeling of exhaustion
11 Insignificant pain

The numbers 1 to 5 were pooled into one group under the designation Intense pain and the remaining categories were called ' Slight pain'

B Functional limitation

The patients were asked about 10 different daily activities (Table 5) For every activity the subject was asked whether he could perform it and if so whether it was with or without pain aggravation

Table 5 The inquiry form about difficulties to carry out ten daily activities Four alternative answers were possible. 1) No difficulties, 2) Painful but possible 3) Not possible owing to pain and 4) Uncertain.

Walking
Walking in stairs
Running
Stooping over a wash basin
Carrying a bag
Making a bed
Riding in a car
Going to the theatre or cinema
Participating in sports
Sitting for a longer period of time

Table 4 Vocational questionnaire – alternative answers

	1	2	3
Mechanical stress postures	**Often**	**Sometimes**	**Rarely**
Sitting standing	≥ 4 hours/day	2–4 hours/day	< 2 hours/day
Bending twisting lifting ≥ 5 kg	≥ 10 times/day	< 10 times/day	a few times/day
Lifting ≥ 20 kg	> once/hour	≤ once/hour	a few times/day
Forceful movements	≥ 10 times/day	< 10 times/day	a few times/day
Vocational exhaustion			
Back fatigue	never	now and then	daily
General fatigue	none	slight fatigue	daily exhaustion
Nervousness	never	sometimes	daily
Variation concentration breaks			
Variation in working tasks	none	repetetive but somewhat varied	varied
Variation in working postures	none	a few fixed postures	optional postures
Breaks	rarely	a few times/day	> once/hour
Concentration required	all day	occasionally	none
Satisfaction			
Working tasks	good	fair	bad
Environment	good	fair	bad
Colleagues	good	fair	bad
Monotony	varied	fairly varied	monotonous

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Lateral flexion was measured by plotting one mark on the iliac crest and one mark on a horizontal line through the xiphoid process in the mid axillary line of the trunk The distance between the two marks was measured in standing erect and in maximal lateral flexion The difference of the distances represented the lateral flexion of the spine

Extension was measured by using the same marks as in lateral flexion A thread with a pointed weight was held so that the point of the weight co-incided with the lower mark The patient was then asked to bend back wards as much as possible The pointed weight traversed the flank The distance was measured as representing the spinal extension

Rotation was measured with a goniometer with the patient sitting.

Straight Leg Raising test (SLR) was defined as pain in the back when raising passively the straight leg

The abdominal muscles were tested by the ability to do sit ups The pa-tient was placed in a supine position with his knees flexed at 100° Nor mal strength of the abdominal muscles was defined as a sit up without using the hands or moving the feet.

The back muscles were tested with the patient in a prone position on the bench of examination The ability to lift the trunk from the bench was defined as normal back muscle strength.

The presence of fixed or impaired gait was registered A neurological ex amination including sensibility in the legs strength of the great toe ex tension and patellar and achilles tendon reflexes was carried out At the initial assessment the neurological status was always normal, owing to the criteria for the patient selection

Forms for psychological tests

The Hysteria (Hs) and Hypochondriasis (Hy) *scales* have been isolated from the Minnesota Multiphasic Personality Inventory (MMPI) (Hatha way & McKinsley 1967) These *scales will* from now on be called the Hs and Hy scales. Earlier experience of this test in studies of low back pain is reported on page 17-19 The isolated scales were modified for a Swedish population by exclusion of *certain* questions In its modified form the questionnaire comprised 56 questions altogether At the six month ex

C Quality of pain

Questions were asked to determine whether the pain was continuous or only felt in connection with movements and strains, and whether it caus ed sleep disturbances or was aggravated by coughing or sneezing

Reassessment

The patients were asked about the duration of back pain and the duration of sick leave since the last investigation If the initial episode of back pain still persisted, the patient was asked the same questions about pain inten sity, functional limitation and quality of pain as in the form used at the initial examination If the patient had developed sciatica, this was also noted If the initial episode had subsided the patient was asked about re lapses and about the occurrence of lumbar insufficiency since the last ex amination The patient was considered to have an episode of back pain if he had continuous or episodic pain in his back every day, and all patients fulfilled this criterion at entry to the study If he only had a feeling of weakness in his back, or pain only on exertion, not causing daily pain, he was considered to have lumbar insufficiency

Form for objective findings

The localization of the pain was plotted on a map The presence of pos tural scoliosis, muscle spasm and pain on palpation and percussion was registered

The range of motion and aggravation of pain in the different planes of motion were registered Flexion, lateral flexion and extension were measured by Schober's modified method, as modified by Moll and Wright (1971)

Flexion was measured by plotting marks on the following locations of the patient s back

1 The lumbosacral junction ('the spinal intersection of a line joining the dimples of Venus')

2 Ten cms above and 5 cms below the lumbo sacral junction

The distance between the upper and the lower marks was measured in standing erect and then in maximal flexion The difference between the distances represented the ability to flex the spine

Analgesics

Only in case of need the patients were provided with analgesics. The choice of analgesics was standardized to either salicylates paracetamols or a combined analgesic (Doleron® * Astra)

METHODS OF TREATMENT

Back school – M Zachrisson Forssell

The Back School was put together and initiated by Marianne Zachrisson Forssell Registered Physiotherapist at the Department of Orthopaedic Surgery at Danderyd Hospital in 1970 It is based on research on the etiology of low back pain intradiscal pressure measurements, EMG and epidemiological studies

Aims and procedure

The Back School is divided into four 45 minute sessions during a 2 week period under the supervision of a physiotherapist Between 6 and 8 patients participate in each course and all patients are given thorough information about the Back School at their first appointment at the clinic The instruction at the Back School is carried out by means of a sound slide program "The Back School" A plastic skeleton flipover charts and other practical aids such as cleaning materials boxes weights etc are also used

First lesson

The first lesson starts with a presentation of the contents of the whole course and the patients are told that they will be given a test of their knowledge at the end of the course They are told this at an early stage in order to stimulate their active attention

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* Acid acetylsalicyl. (2-diaethylaminoaethyl.) phenthiazincarboxyl.-(10)-chlorid constit q s. dextropropoxiphen chlorid coffein phenazon. constit obd

amination the Eysenck Personality Inventory (Bederoff Petersson et al 1968) was administered to the patients This inventory included a neuroticism scale, an extroversion scale and a lie scale

Additional data

The patients sociomedical circumstances have been further elucidated by information obtained from the social workers employed at Volvo Any contact with the social workers was registered, and whether the contact had occurred before or after 1974, and the reason for the contact was noted

Information about the total amount of sick listing under various diagnoses during a period of 2 years before entry to the study was obtained for each patient from the National Health Insurance Office (NHIO) The patient s own statement as to his sick listing for back pain during the time of the study was also checked with the NHIO

"Pain index'

In order to describe changes in pain of the population studied a "pain index' was introduced The "pain index" was based on several of the questions regarding pain as listed in Table 6 The inquiries were provided with scores arbitrarily chosen by the investigators An attempt was made to range the scores according to the intensity of pain The range of scores of the "pain index' was 0 – 70 points (0 = no pain, 70 p = a maximum of pain)

Table 6 Questions about pain with scores giving rise to the »pain index» The range of scores = 0 – 70 points

	No		Yes
»Intensive pain»	0		15
Sleep disturbing pain	0		5
Continuous pain	0		5
Increased pain when coughing and sneezing	0		5
Increased pain when flexing back	0		10
Increased pain when extending back	0		10
Functional limitation (10 questions each ranging from 0 – 3 points)	0	–	30

Participation in various types of physical activity and sports is encouraged in order to improve psychological and physical tolerance to pain and stress

Finally the patients are examined to see how much they have learnt from the course and to give the physiotherapist an opportunity to clear up any misunderstandings

The patients are on the same occasion provided with a written summary of the prin cipal contents of the Back School.

Additionally patients attending the School are also offered one session of pool exer cises under the supervision of the physiotherapist The exercises are individually ad just d to the condition of each patient.

In this trial 70 patients were allocated to the Back School at random None of the patients was absent from any of the four lessons.

The physiotherapist finally made an analysis of the working conditions by visiting the patient s work site for about an hour The physiotherapist was well acquainted with the working conditions since before the begin ning of the trial she was doing assembly line work for a considerable time Improper working postures were when possible corrected The physiotherapist did a follow up visit at the work site two weeks later for about half an hour to see whether the patients still succeeded in follow ing the instructions given

Certain tasks of work could not be carried out in proper working pos tures owing to the construction of the work site Suggestions were then made to the work managers on adjusting the work sites in order to im prove the working conditions for the back patients.

If immediate changes were not possible attempts were made to transfer the patients to another work site if the condition of the back so required

Ten patients changed occupation during the year of observation owing to their back disorders

Combined physical therapy – B Malmstrom A Zellman

The patients in the combined physical therapy group were treated by re gistered physiotherapists specially trained in manual therapy This ther apy is based on methods *developed by Dr J* Cyriax (1959) England (gen eral diagnosis) the Norwegian physiotherapist F Kaltenborn (1975) (ex amination and treatment) and dr *Karel Lewit (1977)* Czechoslovakia

Different aspects of back disorders are discussed, including their occurrence and which patients suffer pain and when and it is emphasized that many people have the symptoms periodically The patients are given full details of the anatomy and function of the back and the results of research and studies on back pain Various methods of treatment are discussed and the body s natural capacity for healing is emphasized The fact that decreased strain on the back somewhat relieves the painful back is also emphasized It is also stressed that increased strain on the tissues gives an increase in symptoms It is therefore important that the patients learn right from the beginning the most restful position during rest the Semi Fowler position The entire instruction therefore takes place in this position instead of in the seated position which in itself is a more strenuous position for the back

Second lesson

During the second lesson the mechanical strain in different positions and during different movements is discussed and the influence of the centre of gravity on the strain on the back is explained The function of the muscles and their influence on the back is demonstrated The patients are instructed in isometric abdominal muscle exercises and encouraged to continue these exercises as the only programme of home exercises every day for the rest of their lives (The exercises take 40 seconds to perform) Back muscle exercises are discussed and the patients are told that these exercises expose the back to increased strain with a risk of aggravation of the symptoms

Third lesson

The third lesson consists of practical application of the previously acquired theoretical knowledge and is the most important part of the Back School in order to give the patient the confidence needed to eliminate factors unfavourable to his back

Two common unfavourable working postures are analysed in detail In the seated position support should be provided behind (by means of a back rest) or in front of the body but an alternating position is preferable Working in the standing position leaning forwards, is just as bad as the seated position as regards strain but the strain can be lessened by using various aids and distributing the body weight

The patients are asked to describe their own work situations and the group endeavours to arrive at a more suitable solution for each individual

Special attention is devoted to lifting techniques Strong leg muscles are a prerequisite for consistent use of a correct lifting technique i e with the knees bent Exercises for strengthening the leg muscles are therefore included

In order to enable the patients to get into and out of bed even during periods of acute pain, they are also trained in this manoeuvre Patients are instructed to rest on their beds in the Semi-Fowler position frequently during acute back pain and to avoid strain

Fourth lesson

The fourth and final lesson mainly consists of encouraging the patients to increase their level of physical activity during leisure hours in spite of their back disorder The advantages of starting physical training in water are emphasized The supportive effect of water contributes to a relief of pain and its constant resistance is regarded for fitness training

Sitting

The position of the spine is checked once again and tests are carried out to see whether any scoliosis due to leg shortening disappears and whether the patient can sit up straight or adopts a special posture due to pain The rotation of the upper half of the body with the pelvis fixed is also investigated The patient sits astride the treatment bench The rotation is tested a tively pas ively and against resistance The main factor investigated in the passive tests is whether the spine permits a slight additional elastic stretching in the extreme position Pain in any rotational direction shows which movement should be avoided during the investigation particularly in the lateral position

Prone

Kibler s test is the first test performed in this position A fold of skin on each side of the spinal process is rolled up the spine between the thumbs and index fingers A positive finding (a distinct change in consistency of the skin with or without pain) suggests engagement of the corresponding segment dermatome myotome or sclerotome A springing test for control of the elasticity between the vertebrae is also performed The index and middle fingers are placed stepwise over the transverse process of each vertebra. With the other hand placed over the fingers light pressure is applied in the ventral direction Positive Kibler s test findings such as a dermatome myotome or sclerotome will now be discernible A normal elasticity between the vertebrae in spite of pain is a stronger indication of a myotome if several pairs of vertebrae are engaged and the muscle itself feels hard A dermatome is more local and shows segmental extension Lack of elasticity between one or more lumbar vertebrae must be further investigated in the lat ral position

Hyper or hypomobility in the iliosacral joints is investigated Manual pressure is appli d di ta'ly over the acrum in the ventrocranial direction and the two iliosacral joints are palpated alternately and compared Slight elasticity should normally be detectable between the edges of the joint surfaces If hypomobility is present the joints feel inelastic and hard and they are usually painful. The hypomobility in the iliosacral joint can be confirmed by pa sively lifting one leg during simultaneous fixation of the sacrum If the leg on the same side as the suspected hypomobile iliosacral joint feels heavier and cannot be lifted up as high as the other leg the findings are positive This is known as Mennell s test

In hypermobility the elasticity in the joint is considerably increased and is often associated with pronounced pain

The above tests for hyper and hypomobility pla e great demands on the therapist's palpation sensitivity

Any tension in the piriform muscle or pain from th origin of the iliac muscle is palpated The psoas and rectus femoris muscles are investigated to see whether they are shortened or contracted due to pain

According to Janda the function of the above muscles is mainly postural i.e they react to incorrect movements by contracting. The elasticity of the muscles and joints is tested in the prone and the supine positions (see below) If the elasticity in the iliosacral joints is normal but the patient experiences pain during passive lifting of the leg and extension is restricted a pure muscle reaction should be suspected The elasticity of the rectus femoris muscle is tested by flexion of the knee

(especially the pelvic examination and diagnosis) Where this was adequate, the patients in this group were treated with manual therapy and in accordance with the methods developed by Dr V Janda (1975), Czechoslovakia, who has made special studies of the muscular system He has concentrated his attention to the muscles with mainly postural function and which contract as a result of incorrect movements and strain He also refers to muscles with mainly phasic function and which react with inhibition and weakening According to Janda these incorrect muscle movements often lead to back symptoms

The patients were also given a five minute information on lifting technique and on the importance of avoiding strenuous movements

Methods of examination

The treatment is based on a thorough investigation in order to be able to arrive at as specific a diagnosis as possible on the basis of the various tests described below

The investigation comprises the active and passive mobility in the patient s back and adjacent joints and also isometric muscle tests The treatment given depends on which structure or structures (muscles joints ligaments or discs) that cause(s) the symptoms

The patient is investigated standing up sitting with his pelvis fixed lying prone supine and in the lateral position

Standing

The patient is undressed and inspected from the front back and side for control of static posture any difference in leg length the position of the pelvis lordosis kyphosis scoliosis and the position of the head and shoulders Walking on the toes and heels and Trendelenburg s test are also carried out The patient is asked to lean backwards sideways and forwards until pain occurs for control of the curvature of the spine investigation for scoliosis and lateral deviations when leaning forward due to pain The spine is also investigated during the active movements for signs of rigid segments indicating hypomobility or excessively mobile segments indicating hypermobility The distance between the fingertips and floor when the patient leans forwards is measured

If pelvic imbalance or a difference in leg length is suspected the patient is placed on two scales Any difference in the load is measured and one or more plates are placed under the shorter leg in order to test whether balance can be restored

To distinguish between true leg shortening and pseudo shortening due to rotation of the pelvis (i e one half of the pelvis is rotated forwards or backwards in relation to the other half) additional tests are performed in the prone and supine positions (see below)

Sitting

The position of the spine is checked once again and tests are carried out to see whether any scoliosis due to leg shortening disappears and whether the patient can sit up straight or adopts a special posture due to pain The rotation of the upper half of the body with the pelvis fixed is also investigated The patient sits a tride the treatment bench The rotation is tested actively passively and against resistance The main factor investigated in the passive tests is whether the spine permits a slight additional elastic str tching in the extreme position Pain in any rotational direction shows which movement should be avoided during the investigation particularly in the lateral position

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Supine

A straight leg raising test (SLR) is done and if this causes lumbar pain a forced test is performed i e the foot is dorsiflected passively and the patient flexes his neck actively A positive SLR between 0 and 30° in the hip joint with increased radiation of pain to the lumbar region and along the sciatic nerve below the knee when the joint is forced also indicates root engagement Pain behind the knee and in the back of the thigh often bilaterally, during passive leg lift above 45° indicates pseudo-positive SLR due to shortening of the hamstrings

According to Janda these muscles — biceps femoris, semimembranosus and semitendinosus — also belong to the group with mainly postural function If the patient is able to flex the hip joint to 80° with his leg straight the elasticity of the hamstrings is normal

For investigation of the hip joint, maximal flexion with the knee bent is checked and inward and outward rotation and adduction (Downing s test) are tested at 90° flexion

In Patrick s test for abduction the leg is allowed to fall outwards with the knee flexed and the foot level with the knee of the other leg with fixation of the superior anterior iliac spine on the opposite side to prevent movement of the pelvis In all these tests the two sides are compared Positive findings in Patrick s and Downing s tests i e reduced mobility often combined with pain suggests blockage in the iliosacral joint if the findings for the hip joint in other tests are normal

Positive findings in Patrick s test may also be caused by contraction of the short adductors (mainly postural function) In this case the mobility will be fairly equal in the two hip joints during abduction and the patient will experience tightness in these groups of muscles

The ligamentous apparatus of the pelvis is also tested particularly the iliolumbar dorsal iliosacral and sacrotuberal ligaments

In this test the ligament is first exposed to passive stretching With the patient in the supine position the test leg is adducted at the hip with the knee flexed The degree of flexion and adduction in the hip joint depends on which ligament is to be tested The ligament is stretched by applying pressure to the adducted leg in the longitudinal direction of the femur for about 20 seconds An increased dull pain over the iliosacral joint or in the groin may be a positive finding

Leg length is investigated once again if earlier tests of the pelvis indicated hypomobility with or without rotation To confirm this the following test is performed If the pelvis is rotated the legs become longitudinally displaced relative to one another when the patient sits up from the supine position with his legs straight The medial malleoli are used as reference points In a positive test one leg is displaced relative to the other and primary restriction of mobility is then almost always present in the pelvis and not in the lumbar spine This is known as the Yo-Yo test

Any radiation of the pain and abnormal sensibility is noted The strength of the rectus abdominis and obliquus muscles is checked and the iliopsoas muscle is investigated for contraction If the test in the prone position gave reason to suspect contraction the following test is performed The patient sits on the edge of the treatment bench lifts one leg and holds it flexed against his chest in order to fix his pelvis The patient is then helped into the supine position The leg being tested hangs

freely and relaxed If the psoas muscle is normal the thigh will hang below the hori zontal line and if the rectus femoris muscle is normal the knee can be flexed to 90° without causing flexion of the hip joint (to compensate for knee flexion)

Lateral position

With the patient in the lateral position the specific mobility between the spinal processes is investigated A palpating finger is placed stepwise between two spinal processes and the patient s flexed leg is held with the other hand By lordosing and kyphosing the patient s lumbar spine alternately it should be possible to feel the spinal processes moving apart and towards each other A positive finding between two processes means too much (hypermobility) or too little (hypomobility) move ment between the spinal processes compared to the movements in other segments.

It will often be found that the segment above or below a hypomobile segment is hypermobile Conversely the segment above or below a hypermobile segment is often hypomobile

After completion of the extension flexion investigation the patient s lower leg is moved towards the ceiling and the floor with the hip and knee joints still at an angle of 90° This leads to a sidebending of the lumbar spin which is also palpated be tween the spinal processes. Finally the patient s pelvi and leg are held still and his spinal processes are palpated while he is made to perform rotational movements with his trunk All these tests are carried out in the least painful direction as indicated by findings in the standing or seated position

In general, the investigation in the lateral position is performed with the patient lying on the painful side Thus if the pain radiates down into the left leg the patient lies on his left side

The findings of the investigation are assessed and the patient s treatm nt is individualized on the basis of these findings

Treatment

Patients with pronounced pain sometimes in connection with postural scoliosis and difficulty in walking have been taught how to *lessen the strain* on their back. When the pain begins to decline the patient returns for more specific tests and is treated in accordance with the findings.

Patients with restricted mobility are given mobilizing treatment for the hypomobile area Mobilization preferably means that *only th hypomobile segment* is moved passively (articulated) the adjacent mobile segments being fixed This is usually done with the patient in the lateral position *when the lumbar* spine is engaged

Patients with hypermobile segments are given stabilization exercises and a strict back regimen described below including information on how to sit down and get up out of a chair how to sit properly how to choose a suitable chair etc The stabilization exercises consist of the therapist applying *manual* pressure in certain directions and the patient responding by pushing back This is done in various positions starting with the individual s gment and *gradually* increasing the number of segments until the whole of th lumbar spine is stabilized

The aim of this treatment is to train the patient to stabilize certain parts of his back reflexively with his muscles and thus prevent the hypermobile parts from coming in to the extreme position and causing pain The patient is taught to work from his hip joints

Patients with a blocked iliosacral joint are treated with gapping The patient lies on the side in which the iliosacral joint is blocked (e g the left side) His left ilium is then fixed and his right leg is flexed at the hip joint The therapist holds the sacrum and right ilium fixed with one or both hands and places her finger tips just medial to the left iliosacral joint The patient performs a maximal right rotation of his trunk and body and tries to look at the floor while taking a deep breath and slowly breath ing out through his mouth Gapping occurs at the movement of relaxation caused by exhalation The effect can be checked immediately by repeating the passive leg lift test with the patient in the prone position If both legs are equally heavy and exten sion is increased the procedure has been successful

Patients with a rotated pelvis are treated with articulation In cases in which the left ilium is rotated forwards (it is actually the sacrum that has rotated around its own axis) the patient is placed on his right side with his right leg fixed in extreme extension in order to lock the right ilium with the iliofemoral ligament The left hip joint is flexed and the therapist presses backwards on the superior anterior iliac spine with one hand and pulls on the ischial tuberosity with the other This results in a rotational movement in the left iliosacral joint A positive effect can immediately be detected by performing the Yo Yo test both legs now have the same length both when the patient is lying down and when he sits up Restitution of the balance can also be checked by placing the patient on two scales

Patients with contraction of postural muscles are given stretching exercises for the groups of muscles concerned For stretching of for example the hamstring muscles of the right leg the patient is placed in the supine position and his right hip joint is flexed until tightness occurs in the back of the knee and/or until the pelvis begins to rotate The patient is then made to perform a maximal isometric contraction of the hamstring muscles for 5 – 6 seconds against manual resistance This is followed by total relaxation during which the leg is immediately flexed passively at the hip joint with the pelvis firmly fixed and the leg straight It is important to avoid the slightest abduction adduction or rotation in the hip joint The leg is held in this new position for up to 20 seconds The exercise is repeated 4 – 5 times each time in the new starting position that the increased elasticity of the hamstring muscles allows The passive stretching occurs during the muscle s refractory period

These exercises which the patient also performs at home using a somewhat differ ent technique but according to the same basic principles must not be carried out in the morning Through this special stretching technique several of the normal pro tective mechanisms of the muscle are put out of action Fine coordination through the gamma system does not function satisfactorily until some hours after the indi vidual gets up

Patients with weak muscles are of course given static and dynamic exercises to in crease their strength

72 patients were allocated at random to the above described treatment Four patients never came to treatment The non treated patients were included in the physiotherapy group in all analyses except the estimation of the duration of symptoms following the first treatment.

The number of treatments in the physiotherapy group were maximized to ten The average number of treatments given were four

Table 7 shows the clinical findings and subsequent treatment of 68 patients assessed by the physiotherapists

Placebo

Short waves of the lowest possible intensity has been the third method of treating a group of patients The heat produced at this intensity may, at the most increase the local blood flow of the subcutaneous tissues (Hovind & Nielsen 1973)

This treatment has therefore been regarded as a placebo

75 patients in this study were randomized to this third group 59 patients followed the treatment

A maximum of ten treatments was given to each patient The average number of treatments given were five

The non treated patients were included in the placebo group in all analyses except the estimation of the duration of symptoms following the first treatment

Table 7 Distribution of clinical findings and subsequent treatment in the physical therapy group – The therapists assessment

Diagnosis	No	%	Treatment[1]
Hypomobile lumbar segment	11	16	1 *Articulation of hypomobile segment with simultaneous fixation of adjacent segments* 2 Specific movement promoting active exercises of the engaged segments
Hypomobile lumbar segments and shortened postural muscles	6	9	1 Articulation 2 Specific movement promoting active exercises 3 Stretching of shortened postural muscles
Hypomobile sacro-iliac joint	8	12	1 Gapping with blockade 2 Articulation with rotated pelvis
Hypomobile sacro-iliac joint and shortened postural muscles	4	6	1 Gapping or articulation 2 Stretching of shortened postural muscles
Hypomobile lumbar segment and hypomobile sacro iliac joint	9	13	1 Articulation of hypomobile lumbar segment 2 Gapping or articulation of hypomobile sacro-iliac joint 3 Specific movement promoting active exercises
Hypomobile lumbar segment hypomobile sacro iliac joint and shortened postural muscles	4	6	1 Articulation of hypomobile lumbar segment 2 Gapping or articulation of hypomobile sacro-iliac joint 3 Stretching of shortened postural muscles 4 Specific movement promoting active exercises
Disc engagement	8	12	1 Pain relief *a) analgesics* b) unloading resting position usually Semi-Fowler position 2 Test traction
Muscular disorders	15	22	According to clinical finding one or a combination of the following alternatives 1 Heat 2 *Stretching of shortened postural muscles* 3 Isometrical strengthening-exercises of weak muscles 4 Exercises of endurance 5 Exercises of coordination 6 General physical exercises
Inflammation of the dura mater	3	4	Antiphlogistics

[1] The methods of treatment are mentioned in the same order as they are performed on the patients

STATISTICAL METHODS

Stratification and randomization

Stratification of the patients was based on vocational and psychologic factors The vocational and psychologic forms described on pages 23 27 were filled in by the patient at the screening assessment and given a score according to a standardized pattern The vocational questionnaire scored from 10 – 30 points The hs and hy scales had scores from 0 – 41 points and 0 – 31 points respectively

Every score above or below a middle value of each scale was given a code

Depending on the scores of the questionnaires each patient was at last provided with one of eight possible combinations of codes. The eight combinations of codes were used when randomizing the patients to one of three modes of therapy Separate tables of random numbers were used for each combined code

Evaluation of results

When estimating the relation between certain confounding factors and certain criterion variables the data was arranged in the form of contingency tables from which chi-square test was carried out The median values of the criterion variables were used in the contingency tables for the calculations with chi square test. The median values were chosen due to a skew distribution of the criterion variables

Contingency tables and chi-square test were also used when comparing absence from work number and length of recurrences in one year in the three groups of therapy

When estimating the differences in ' pain index between the treatment groups an analysis of variance was performed and contrasts of the differences between the three groups were constructed

A covariance analysis was used when comparing the duration of symptoms following the first treatment in the three groups. The covariance analysis was used to see whether possible effects of any of the treatments could be explained by differences in time between the onset of symptoms to the first treatment in the treatment groups.

The test functions of covariance analysis require underlying normal distributions and as the distribution of the duration of the initial episode was rather skew logarithms of the values were used.

EVALUATION OF RESULTS

Results Part I

The profile and the clinical manifestations in the 217 patients are presented in Part I, by means of frequency tables

Results Part II

The influence of certain confounding factors on the course of acute and subacute low back pain is assessed by relating the confounding variables to

1 The duration of the initial episode
2 the duration of sick leave during the initial episode,
3 the summarized duration of recurrences of pain in one year, and
4 the total absence from work in one year owing to recurrences

Results Part III

The efficacy of the three different modes of treatment for acute and subacute low back pain is evaluated by comparing

1 The duration of symptoms following the first treatment
2 the length of absence from work during the initial episode
3 the variation in experience of pain during the initial episode by means of the "pain index" (see Methods page 28)
4 the number of recurrences in one year,
5 the length of recurrences in one year, and
6 the total absence from work in one year owing to recurrences

RESULTS PART I

PATIENT PROFILE

Age and sex

The distribution by age and sex in the studied population is illustrated in Fig 1 13 % of the patients in the study were women while 20 % of the employees at Volvo Gothenburg are women

The youngest patient in this study was 17 years old and the oldest was 64 years of age The median age was 34 5 years

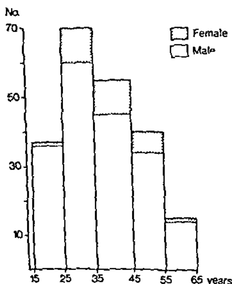


Fig 1 Age and sex distribution of the patients

History of back pain

43 % of the patients reported no previous episodes of back pain 32 % had had back pain only once before while 25 % of the patients had had more than one episode of back pain Table 8

EVALUATION OF RESULTS

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The efficacy of the three different modes of treatment for acute and sub acute low back pain is evaluated by comparing

1 The duration of symptoms following the first treatment
2 the length of absence from work during the initial episode,
3 the variation in experience of pain during the initial episode by means of the ' *pain index* ' (see Methods page 28)
4 the number of recurrences in one year
5 the length of recurrences in one year, and
6 the total absence from work in one year owing to recurrences

Duration of symptoms before entry to the study

The time between the onset of back pain and the initial assessment of the patient ranged from 1 to 86 days Most patients (83 %) had had their back pain for less than three weeks at the first examination The median duration of symptoms of the studied group before entry to the study was 9 days The duration of symptoms before entry to the study is shown in Table 10

Table 10 Duration of symptoms before entry to the study

Duration of symptoms	Number of patients
Less than 1 week	79
1 to 2 weeks	63
2 to 3 weeks	37
3 to 4 weeks	11
4 to 8 weeks	25
More than 8 weeks	2

Subjective symptoms

The pain was considered intensive by 67 % and not intensive by 33 % of the patients according to the ten possible answers to the questions regarding pain Continuous pain during the day was reported by 49 % while the remaining patients stated that pain occurred only in connection with movements or strain Some pain at night was experienced by 40 % but only 23 % of all the patients reported sleep disturbances The pain was accentuated by coughing and sneezing in 42 % of the patients The characteristics of pain in the group of patients are presented in Table 11

Table 8 The occurrence of previous episodes of back pain.

Number of episodes	Number of patients
None	93
One	69
Two	15
Three	10
More than three	27
Information lacking	3

Onset of current episode of back pain

The onset of back pain was sudden in 44 % of the group while 56 % of the patients reported a more insidious onset 42 % stated that the symptoms had started during working hours and 51 % of the patients reported that the pain first occurred during leisure time 7 % were unable to relate the onset of their symptoms to time In 45 % of the patients the symptoms appeared in connection with a specific incident i e bending, twisting lifting, a sudden movement or a fall The circumstances of the onset of symptoms are shown in Table 9

Table 9 Circumstances of the onset of back pain.

		Number of patients
Type of onset	sudden	96
	insidious	121
Time of onset	working hours	92
	leisure time	110
	uncertain	15
Incident related to onset	none	119
	a fall	2
	a lift	36
	bending	34
	a sudden movement	7
	other incident	17
	information lacking	2

Location of pain

All the patients had pain in the lumbar region The pain was mainly located centrally in the lower lumbar area or in the paravertebral region as illustrated in Fig. 2 Pain in the gluteal region or the thigh occurred in 26 % of the patients Pain was more common in the right gluteal region and thigh than on the left side

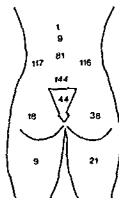


Fig 2 Location of pain in the studied patients Combination of the locations of pain is possible Figures = number of patients.

Objective findings

The Straight Leg Raising test (SLR) was performed The test was positive unilaterally in 27 % and bilaterally in 35 % of the patients Only 14 % of the patients had an SLR below 60°

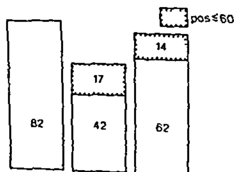


Fig 3 The straight leg raising test

Table 11 Characteristics of pain

	Number of patients			
	Yes	No	Uncertain	Total
Intensive pain	145	72	0	217
Continuous pain	106	111	0	217
Night pain	86	131	0	217
Sleep disturbances	49	168	0	217
Accentuation of pain when coughing and sneezing	92	105	20	217

The degree of functional limitation due to back pain with respect to ten activities of daily living is listed in Table 12

Table 12 Functional limitation of activities of daily living

	No increase of pain	Uncertain if the pain increased	Increase of pain but can be done	Cannot be done because of pain
Walking	124	2	86	5
Walking up stairs	82	24	109	2
Carrying a bag	75	62	71	9
Riding in a car	63	24	128	2
Sitting	42	0	159	16
Going to a theatre or cinema	36	8	58	115
Stooping over a wash basin	10	0	174	33
Making a bed	9	61	107	40
Running	13	51	56	97
Participation in sports	1	14	18	184

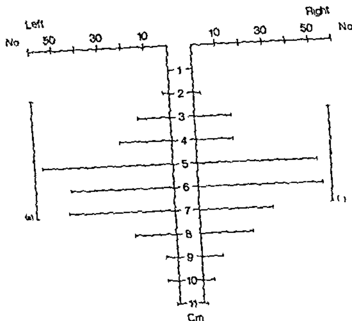


Fig 5 The range of lateral flexion (a) = mean values of lateral flexions ± 2 s d in a normal population of 35 year-old males

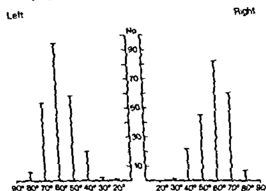


Fig 6 The range of rotation

The presence of postural scoliosis paravertebral muscle spasm and tenderness on palpation and percussion was *registered* Less than 20 % of the patients had pronounced paravertebral muscle spasm and postural scoliosis

Tenderness on palpation was registered in 60 % and tenderness on percussion in 39 %.

Impaired and fixed gait was present in 9 % of the patients.

The range of flexion, extension, and lateral flexion, measured by a modification of Schober's method, and the range of rotation are presented in Figs 4 – 6 Values for a normal population of 35 year old males are inserted in the figures These values were taken from a study by Moll and Wright (1971) who used the same method A decreased ability to bend forwards was observed in the studied group of back patients compared with the values of the normal population The range of extension and lateral flexion did not differ from the values obtained in the normal population

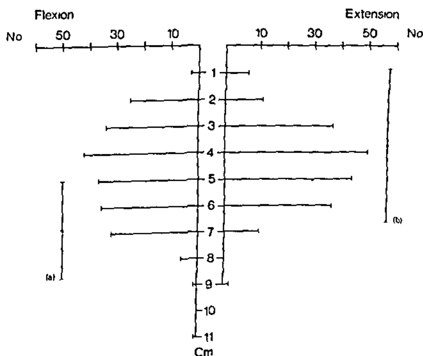


Fig 4 The range of flexion and extension. (a) = mean value of flexion ± 2 s d in a normal population of 35 year-old males (b) = mean value of extension ± 2 s d in a normal population of 35 year old males

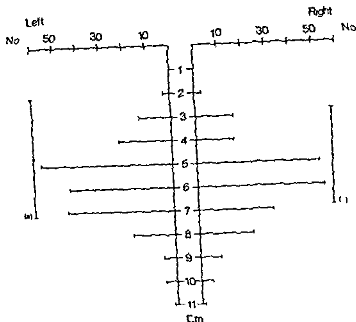


Fig 5 The range of lateral flexion (a) = mean values of lateral flexions ± 2 s d in a normal population of 35 year-old males

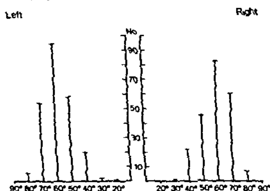


Fig 6 The range of rotation

The presence of postural scoliosis paravertebral muscle spasm and tenderness on palpation and percussion was registered Less than 20 % of the patients had pronounced paravertebral muscle spasm and postural scoliosis.

Tenderness on palpation was registered in 60 % and tenderness on percussion in 39 %

Impaired and fixed gait was present in 9 % of the patients.

Pain was registered in the planes of motion as well as when doing sit ups and back lifts An increase of pain when bending forwards was reported by 89 % of the patients while increase of pain was not so frequent in the other planes of motion The additional clinical findings are presented in Table 13

Table 13 Additional clinical findings.

Clinical findings		Number of patients Yes	No
Postural scoliosis		40	177
Muscle spasm		38	179
Impaired fixed gait		20	197
Pain on palpation		129	88
Pain on percussion		84	133
Increase of pain on	flexion	193	24
	extension	157	60
	unilateral rotation	33	184
	bilateral rotation	69	148
	unilateral lateral flexion	72	145
	bilateral lateral flexion	89	128
	doing sit ups	165	52
	doing back lifts	120	97
Reduced ability to do sit ups		185	32
Reduced ability to do back lifts		101	116

Vocational factors

Of the 217 patients 59 were office staff and 158 were manual workers This proportion corresponds well to the proportion of office staff and manual workers at Volvo, Goteborg Fig 7

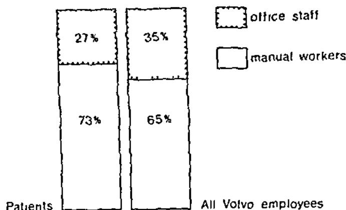


Fig 7 The proportions of office staff and manual workers among 217 patients in relation to the proportions of all employees at Volvo

Of the manual workers 71 were working according to a two-shift schedule while the remaining patients were working a day time schedule The proportions of shift workers and day time workers are compared with the corresponding proportions among all employees at Volvo Göteborg in Fig 8

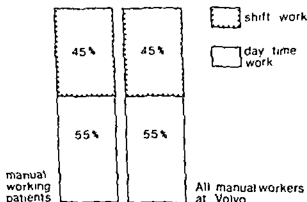


Fig 8 The proportion of daytime and shift workers among the patients in relation to the corresponding proportions at Volvo

The patients assessment of the postures required in their work is shown in Table 14 A predominance of the standing posture for the greater part of the day was reported by the manual workers A fixed posture throughout the working day was reported by 26 % of the patients.

Table 14 Patients answer regarding their working postures Manual workers = m Office staff = o

Working posture	Often No	% m, o	Sometimes No	% m o	Rarely No	% m, o
Sitting★	55	(13, 60)	34	(15 17)	127	(72 23)
Standing	135	(77, 23)	39	(14 26)	43	(9, 51)
Fixed working posture	Fixed		Partly fixed		Varied	
	52	(26, 16)	69	(38 12)	96	(36 72)

★ Data lacking for one patient

The necessity for bending, twisting, lifting and forceful movements, according to the patients, is presented in Table 15 A high frequency of bending and twisting movements was reported by the manual workers while lifting and forceful movements were not considered to be necessary as frequently

Table 15 Patients answers regarding movements required during work Manual workers = m Office staff = o

Type of movement	Often No	% m o	Sometimes No	% m o	Seldom No	% m o
Bending forward	140	(81 19)	34	(14 21)	43	(5 60)
Twisting	140	(79 21)	37	(16 21)	40	(5 58)
Lifting (⩾ 5 kg)	66	(39 5)	62	(36 9)	89	(25 86)
Lifting (⩾ 20 kg)	25	(14 2)	37	(23 4)	155	(63 94)
Forceful movements	25	(15 2)	38	(24 0)	154	(61 98)

Table 16 illustrates the need to concentrate during work the degree of variation in working tasks and the possibilities of taking pauses during work A high proportion of the patients reported a moderate to great need to concentrate during the working day Variation in working tasks was more frequent than no variation Manual workers predominate among patients giving answers representing no necessity for concentration, no variation and no possibility to take pauses during work

Table 16 Variation pauses and need to concentrate during work. Manual workers = m Office staff = o

	Often No	% m o	Sometimes No	% m o	Seldom No	% m o
Concentration necessary	96	(41 51)	87	(38, 47)	34	(21 2)
Possibilities to take pauses during work	76	(29 54)	96	(46 37)	45	(25 9)
	Much		Some		None	
Variation in working tasks	89	(29 74)	78	(42 21)	50	(29 5)

Only a moderate proportion of the patients mainly manual workers experienced daily back fatigue and pronounced exhaustion in connection with their work Very few patients reported nervousness. Table 17

Table 14 Patients answer regarding their working postures Manual workers = m Office staff = o

Working posture	Often No	% m o	Sometimes No	% m o	Rarely No	% m, o
Sitting*	55	(13 60)	34	(15 17)	127	(72 23)
Standing	135	(77, 23)	39	(14 26)	43	(9, 51)
Fixed working posture	Fixed		Partly fixed		Varied	
	52	(26, 16)	69	(38, 12)	96	(36 72)

* Data lacking for one patient

The necessity for bending, twisting, lifting and forceful movements according to the patients, is presented in Table 15 A high frequency of bending and twisting movements was reported by the manual workers while lifting and forceful movements were not considered to be necessary as frequently

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Forceful movements	25	(15 2)	38	(24 0)	154	(61 98)

The length of employment at Volvo is given in Fig. 9 Only 4 % of the patients had been employed for less than one year and 28 % had been employed for more than ten years.

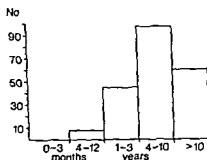


Fig 9 The length of employment

Social factors

Most patients were married or cohabiting and half of them had children below 16 years of age The majority of the patients lived in a flat consisting of more than two rooms Table 19

Table 19 Family circumstances.

	Number of patients Yes	No	Data lacking
Married or cohabiting	168	48	1
Children below 16 years of age	101	107	9
Housing bigger than 2 rooms	154	53	10

Table 17 Back fatigue exhaustion and nervousness after work. Manual workers = m Office staff = o

	Often		Sometimes		Never	
	No	% m o	No	% m, o	No	% m o
Back fatigue during work	28	(17, 3)	106	(52, 37)	83	(31 60)
Nervousness after work★	3	(2 0)	61	(27, 25)	152	(71, 75)
	Much		Some		None	
Exhaustion after work	22	(13, 0)	160	(76 68)	35	(11, 32)

★ Data lacking for one patient

A majority of the patients were satisfied with their working duties, their working environment and their relations with their colleagues Table 18 On inquiry, 63 patients stated that they wished to change their jobs (38 % of the manual workers and 14 % of the office staff)

Table 18 Satisfaction with working duties working environment and relations with colleagues. Manual workers = m Office staff = o

Satisfaction with	Good		Fair		Poor	
	No	% m o	No	% m o	No	% m o
Working tasks	157	(69 86)	50	(25 14)	10	(6 0)
Working environment	116	(50, 65)	87	(42 32)	14	(8 3)
Relations with colleagues	194	(90, 89)	21	(9 11)	2	(1 0)

The tendency to report sick under any diagnosis during two years before entry to the study was registered for the 217 patients The mean duration of sick leave was 15 5 days per year The distribution of sick listing during these two years is shown in Fig 10



Fig 10 Sick listing of all patients during two years before entry to the study

Psychological factors

The scores of the Hy and Hs-scales of the MMPI test are illustrated in Fig. 11 There is a pronounced accumulation around the lowest values of the Hy scale A normal distribution of the Hs-scale was observed although with some shift towards lower values.

Fig 11 Scores of Hs and Hy scales expressed in per cent of the maximal values The range of scores is 0 – 41 points for the Hs scale and 0 – 31 points for the Hy scale

Regular participation in physical exercise was reported by 34 % of the patients and 16 % were actively engaged in some kind of sport

The previous or recent occurrence of psychosomatic symptoms is given in Table 20

Table 20 Psychosomatic symptoms.

Symptoms	Number of patients		
	Yes	No	
Gastric or duodenal ulcer	13	204	
Frequent headaches	12	205	
	Recently	Previously	No
Gastritis, irritable colon	17	65	135
	Often	Sometimes	Never
Palpitations or discomfort in the chest	8	22	187

It was found that 12 % of the patients had had continuous contacts with the social welfare authorities since the start of the investigation in 1974 The reasons for these contacts are presented in Table 21

Table 21 Contact with social welfare authorities.

Reason for contact	Number of patients
Constant financial problems	22
Family problems	8
Difficulties in adjusting	12
Alcoholic problems	7

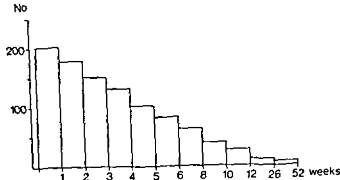


Fig 13 Duration of the initial episode of pain

Duration of sick leave during the initial episode

During the initial episode 34 patients were never sick listed The sick listing of the other 184 patients is presented in Fig 14 68 % of the sick listed patients were back at work within one month. The median duration of sick leave when it occurred was 21 days.

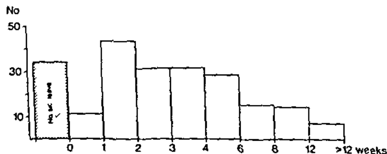


Fig 14 Duration of sick leave during the initial episode

Changes in clinical manifestations during the initial episode

The location of pain

The location of pain at the initial examination and at ten days three weeks and six weeks is given in Table 22

The scores on the scales of extroversion (E), and neuroticism (N) of the Eysenck test are shown in Fig 12 The range of scores for both scales is 0 – 24 points The median score was 12 for the (E) scale and 5 for the (N) scale The lie-scale, ranging from 0 – 9 points, with a median score of 3 5 points, was normally distributed

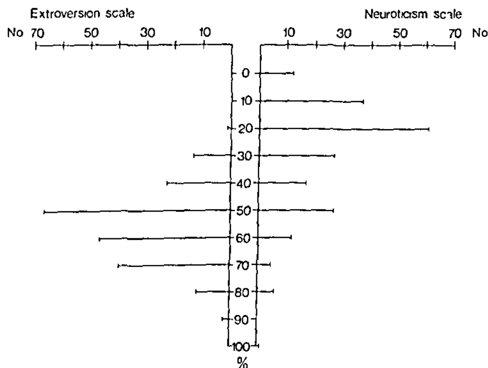


Fig 12 Scores on the extroversion and neuroticism scales of the Eysenck test expressed in per cent of the maximal score The range of scores for both scales is 0 – 24 points

COURSE OF THE DISEASE DURING ONE YEAR

Duration of the initial episode of pain

The time from the onset of pain until the disappearance of symptoms is presented in Fig 13 None of the patients had a duration of symptoms shorter than one week The pain disappeared within one month in 35 % within two months in 70 % and within three months in 86 % of the patients An initial episode of pain lasting more than six months was found in six per cent of the patients, while four per cent still experienced pain after one year The median duration of pain was 35 days

The location of pain at the different assessments was uniform At the six week assessment there was a tendency towards an increased radiation of pain to the thighs

Pain index

The change of pain during the first six weeks after the initial assessment as determined by means of the pain index is shown in Table 23 and Fig 16 There was a marked decrease of the pain index score between the initial and the 10-day assessment indicating relief of pain during this period At the three week examination the median value of the pain index was unchanged while it was slightly raised among those who still had pain at the six week examination

Table 23 The change of pain during six weeks expressed as median values of the pain index scores. The range of scores of the pain index is 0 – 70 points.

	Time of examination			
	Initial	10 days	3 weeks	6 weeks
Median value	42	22	22	27
Number of patients	217	151	86	45

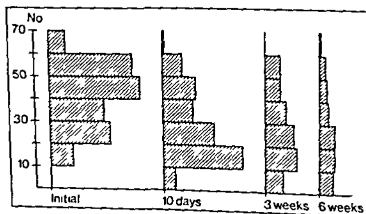


Fig 16 The change of pain during six weeks as determined by means of the pain index The range of scores of the pain index is 0 – 70 points

Table 22 Location of pain during the first six weeks of the initial episode

Location of pain		Time of examination Initial %	10 days %	3 weeks %	6 weeks %
Central pain	A	5	4	3	4
	B	37	38	34	47
	C	66	71	67	80
	D	20	19	12	11
Flank pain	E	54	48	45	47
	F	53	56	47	51
Buttock pain	G	8	12	8	11
	H	18	14	12	18
Thigh pain	I	4	7	6	11
	J	10	6	9	13
No of patients		217	151	86	55

The zones for the location of pain are shown in Fig. 15

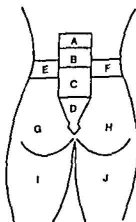


Fig 15 Zones for the location of pain

Total duration of recurrences of pain in one year

The total duration of all recurrences of pain during one year of observation for the 134 patients with relapses is presented in Fig 17 The duration of all recurrences varied from less than one week to 40 weeks The median duration of all recurrences was 27 days.



Fig 17 Total duration of recurrences of pain in one year (n = 134 patients

Total duration of absence from work in one year owing to recurrences

Among all the patients with recurrences of pain 66 patients were never absent from work The duration of sick leave during the recurrences varied from less than one week to 30 weeks Table 26 The median duration of sick leave during all the recurrences was 16 days

Table 26 Total duration of sick leave during all recurrences n = 68 patients

Time (weeks)	0–1	1–2	2–4	4–8	8–30
Number of patients	7	23	17	14	7

Recurrences of pain in one year

Number of recurrences of pain

During the year of observation 62 % had one or more recurrences of pain More than six recurrences were not observed in any of the patients. The distribution of recurrences is illustrated in Table 24 The median number of recurrences was 1 3

Table 24 Number of recurrences of pain during one year of observation

No of recurrences	0	1	2	3	4	5	6
No of patients	83	56	37	23	8	6	4

Time between recovery from initial episode to first recurrence of pain

Of the 134 patients with more than one episode of pain 6 % had their first relapse of pain within 2 weeks after recovery from the first episode In 24 % of the patients the first recurrence occurred after more than six months The median time between the recovery from the initial episode and the beginning of the first recurrence was 63 days Table 25

Table 25 Time between recovery from the initial episode and the beginning of the first recurrence

Time (weeks)	0–2	2–4	4–6	6–12	12–26	>26
Number of patients	8	22	16	26	31	31

RESULTS PART II

INFLUENCE OF CONFOUNDING FACTORS ON THE COURSE OF THE DISEASE

The factors characterizing the patient profile (part I) were related to 1) the duration of symptoms during the initial episode of pain 2) the duration of sick leave during the initial episode 3) the total length of recurrences of pain in one year and 4) the total duration of absence from work due to recurrences in one year

History of back pain

Earlier episodes of back pain

The course of the disease was found not to differ between patients with earlier low back disorders and those who reported no earlier episodes of back pain

Onset of symptoms

A tendency ($p < 0.05$) towards a longer duration of the initial episode was found among patients with an insidious onset compared to those with a sudden onset of pain The course of the disease was not influenced by the type of onset of symptoms in any other way

Clinical findings

"Pain index"

The "pain index", based on the sum of scores of several questions regarding the duration of pain ranged from zero to 70 points

Total duration of low back pain in one year

The duration of episodes of low back pain during one year of observation was calculated. The duration of back pain in one year among 217 patients is given in Fig. 18. During the time of the study 24 % of the patients had back pain for less than one month, 47 % had back pain for less than two months, 66 % for less than three months and 88 % for less than six months. The median duration during one year was 60 days.

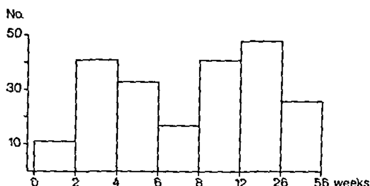


Fig. 18. Total duration of low back pain in one year

Development of rhizopathy

During the time of the study 8 % of the patients developed sciatica resembling rhizopathy, with or without neurological findings. No surgery for disc herniation was carried out.

Development of lumbar insufficiency

In addition to the registered episodes of low back pain, 62 % of the patients had one or more episodes of lumbar insufficiency, i.e. fatigue and discomfort in the back during strenuous movements.

Change of occupation

During this study of 217 patients with acute low back pain 52 % changed their jobs. The back disorders were reported to be the main reason for changing jobs by 32 % of these patients. The transfer took place within Volvo or to another company.

RESULTS PART II

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Clinical findings

"Pain index"

The pain index based on the sum of scores of several questions regarding the duration of pain ranged from zero to 70 points

The patients whose scores were above the median value for the initial examination were found to have a longer absence from work ($p < 0.05$) during the initial episode than the patients with less pronounced pain, according to the index. A high pain score at the initial assessment was found not to prolong the initial episode. However, a much longer initial episode of pain ($p < 0.001$), with a subsequent longer absence from work ($p < 0.001$), was found among patients still afflicted with severe pain at the ten day examination, compared to patients with only moderate pain.

The "pain index" score at the ten day examination was not related to the length of relapses or absence from work in connection with relapses.

Objective findings

No evidence was found of a relation between the course of back pain during the year of observation and the range of motions (flexion, extension, lateral flexion and rotation) registered at the initial assessment. The presence of clinical manifestations, like postural scoliosis and radiation of pain in one or both thighs, did not seem to influence the course of the ailment.

The duration of sick leave during the initial episode was found to be significantly longer ($p < 0.01$) among patients who manifested pain on percussion of the lower lumbar spine. The duration of absence from work during the initial episode was also significantly longer ($p < 0.01$) among patients who had a positive Straight Leg Raising Test (SLR) at the initial assessment.

There were no indications of a relation between the presence of pain on percussion and SLR and the remaining variables determining the course of acute back pain.

Vocational factors

Mechanical strain and working postures

The influence of working postures on the duration of the initial episode was observed among patients who sat less than two hours per day ($p < 0.05$), bent ($p < 0.01$) and twisted ($p < 0.05$) their backs more than ten

times per hour and who were forced into fixed postures ($p < 0.05$) for the greater part of the working day Correspondingly shorter durations were found among patients who sat more than four hours a day who seldom bent or twisted their backs and whose postures varied No relation was found between a longer duration of the initial episode and standing lifting and forceful movements

Patients whose work involved sitting for less than two hours per day ($p < 0.001$) frequent bending ($p < 0.001$) and twisting ($p < 0.01$) movements and lifting ($\geqslant 5$ kg) at least ten times per hour ($p < 0.01$) were absent from work longer during the initial episode No relation was found between longer sick leave and fixed postures standing, lifting ($\geqslant 20$ kg) and forceful movements

Fixed working postures were found to be related to a longer duration of symptoms due to relapses in one year ($p < 0.01$)

None of the other working postures tested showed any relation to the duration of recurrences

A longer duration of sick leave during relapses was related to bending ($p < 0.05$) and twisting ($p < 0.01$) more than ten times per hour as well as frequent forceful movements ($p < 0.05$)

The amount of sitting standing fixed postures and lifting was not related to the length of absence from work during relapses

Vocational exhaustion

A *significantly* longer duration of the initial episode was observed among patients who experienced daily fatique in their backs ($p < 0.01$) before the present episode and *among patients* who were exhausted after work ($p < 0.05$)

No evidence was found of a relation between fatigue and absence from work or recurrences. Only the patients who reported daily nervousness after work exhibited a longer *total* duration of relapses ($p < 0.01$) in a year

The patients whose scores were above the median value for the initial examination were found to have a longer absence from work ($p < 0\ 05$) *during the initial episode than the patients with less pronounced pain,* according to the index A high pain score at the initial assessment was found not to prolong the initial episode However, a much longer initial episode of pain ($p < 0\ 001$), with a subsequent longer absence from work ($p < 0\ 001$), was found among patients still afflicted with severe pain at the ten day examination, compared to patients with only moderate pain

The "pain index" score at the ten day examination was not related to the length of relapses or absence from work in connection with relapses

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Patients whose work involved sitting for less than two hours per day ($p < 0.001$) frequent bending ($p < 0.001$) and twisting ($p < 0.01$) movements and lifting (≥ 5 kg) at least ten times per hour ($p < 0.01$) were absent from work longer during the initial episode No relation was found between longer sick leave and fixed postures standing lifting (≥ 20 kg) and forceful movements

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Variation concentration and breaks at work

A longer duration of the initial episode together with a longer duration of absence from work was registered among patients with repetitive ($p < 0.001$, $p < 0.05$) or monotonous ($p < 0.01$) jobs compared to patients with varied jobs Low requirements of concentration at work were also related to a longer duration of sick-leave during the initial episode ($p < 0.05$)

The number of breaks during the working day did not seem to influence the course of the disease

Job satisfaction

Patients reporting discontent with their jobs were found to have a longer initial episode ($p < 0.01$) and a longer absence from work ($p < 0.05$) than the satisfied patients

Dissatisfaction with the working environment was also associated with a longer duration of absence both during the initial episode ($p < 0.001$) and during recurrences ($p < 0.05$)

Relations with colleagues and a desire to change jobs did not have any significant influence on the course of the disease

Category of employment

The course of the disease was compared between office staff and manual workers because of the different working conditions in the two groups

A significantly longer initial episode ($p < 0.01$), a longer duration of absence during the initial episode ($p < 0.001$) and an increased duration of sick leave during relapses ($p < 0.01$) were observed among the manual workers with correspondingly shorter durations among the office staff

There was no relation between the category of employment and the duration of recurrences

Influence of vocational factors on the course of the disease among manual workers and office staff separately

A separate analysis of the influence of vocational factors was carried out on each category of employees because of the significant differences in the two groups regarding the duration of the initial episode and absence from work The same vocational variables were tested as on the whole population

A significantly longer duration of the initial episode was still observed in manual workers who stated daily back fatigue ($p < 0.5$) and who had repetitive ($p < 0.01$) and monotonous ($p < 0.05$) jobs A longer absence from work during the initial episode was also observed in manual workers who sat less than two hours per day ($p < 0.05$) compared to the manual workers who sat for much of their working day or needed to bend only occasionally

None of the other vocational factors had an influence on the course of the disease when related to each category alone provided that the significance test could be carried out

The influence of most of the vocational factors could not be assessed among office staff separately as the distributions in the alternative answers to the questions asked were highly skewed

Skew distributions were also found among the manual workers in respect of the questions concerning the amount of bending and twisting. Only very few workers were not required to bend and twist frequently at work and the chi-square test could therefore not be applied Similarly it was not possible to evaluate the influence of job satisfaction since the number of manual workers who were discontented with their work was insufficient to be related to the course determining variables

Interrelations between vocational factors

Working postures

Highly significant relations were obtained between standing for more than four hours per day and sitting for less than two hours per day and frequent bending twisting lifting forceful movements and fixed postures ($p < 0.001$)

Variation, concentration and breaks at work

A longer duration of the initial episode together with a longer duration of absence from work was registered among patients with repetitive ($p < 0.001$, $p < 0.05$) or monotonous ($p < 0.01$) jobs compared to patients with varied jobs. Low requirements of concentration at work were also related to a longer duration of sick-leave during the initial episode ($p < 0.05$).

The number of breaks during the working day did not seem to influence the course of the disease.

Job satisfaction

Patients, reporting discontent with their jobs were found to have a longer initial episode ($p < 0.01$) and a longer absence from work ($p < 0.05$) than the satisfied patients.

Dissatisfaction with the working environment was also associated with a longer duration of absence both during the initial episode ($p < 0.001$) and during recurrences ($p < 0.05$).

Relations with colleagues and a desire to change jobs did not have any significant influence on the course of the disease.

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The course of the disease was compared between office staff and manual workers because of the different working conditions in the two groups.

A significantly longer initial episode ($p < 0.01$), a longer duration of absence during the initial episode ($p < 0.001$) and an increased duration of sick leave during relapses ($p < 0.01$) were observed among the manual workers with correspondingly shorter durations among the office staff.

There was no relation between the category of employment and the duration of recurrences.

Eysenck test

Extroversion and neuroticism

High and low scores on the scales of extroversion and neuroticism were compared and related to the course of pain and absence from work during the year of observation Patients having a low score on the scale of extroversion tended to have more days of pain due to relapses in the year of observation ($p < 0.05$) The other scores on the two scales were not found to be course related

Social factors

A significantly longer duration of pain ($p < 0.01$) during the initial episode was found among patients who had had continuous contact with the social welfare authorities since 1974 compared to the patients without any known contact with the social welfare authorities Neither the duration of sick leave nor the total duration of recurrences in one year was related to contact with the social welfare authorities

Previous psychosomatic symptoms

The course of low back pain was not related to affirmative answers to questions concerning previous psychosomatic symptoms

Tendency to report sick

Patients who according to the NHIO were sick listed under any diagnosis for long periods of time during the two years before entry to the study were also absent from work much longer during the initial episode of pain ($p < 0.001$) than patients with a shorter record of sick leave during the two years preceding the study The amount of sick listing during these two years did not influence the sick listing during recurrences or the duration of episodes of back pain during the year of observation

Participation in physical exercise

Patients who regularly participated in physical exercise did not show any dissimilarity in the course of back pain compared to patients who only occasionally or never took exercise

Frequent bending, twisting, lifting, forceful movements and fixed pos tures were all found to be strongly correlated to one another ($p < 0.001$)

Vocational exhaustion

Daily back fatigue was significantly related to exhaustion after work ($p < 0.001$)

Variation and concentration

Highly significant relations were obtained between repetitive work, monotonous work and work involving little need for concentration ($p < 0.001$)

Job satisfaction

The patients who reported dissatisfaction with their jobs were also dis satisfied with their working environment ($p < 0.001$)

Interrelations between working postures vocational exhaustion variation and con centration, and job satisfaction

Significant relations were also obtained between demanding working pos tures, pronounced vocational exhaustion, little variation, low require ments of concentration and discontent with duties and the working en vironment

Psychological factors

The Hy and Hs scales

The course of the initial episode was compared between patients given a score above and below the median value on the Hy scale The patients with scores above the median value (2 points) were absent from work significantly longer during the initial episode ($p < 0.05$) No other differ ences in the course were observed between the two groups The patients who had scores above six points were than compared with the patients with zero points and a significantly longer duration of the initial episode of pain ($p < 0.05$) was found among the patients with scores above six points When the same procedure was carried out on the Hs scale no dif ferences were detected between patients with scores above and below the median value or between groups of patients with extreme scores

Vocational factors				
Category of employment	*	*		
Sitting		* *		
Fixed posture			*	
Bending forward				
Twisting movements	*			
Lifting (≥ 5 kg)				*
Forceful movements				
Fatigue back				
Fatigue after work				
Repetitive work	*			
Monotonous work				
No need to concentrate				
Satisfaction with working tasks		*		
Satisfaction with working environment				
Nervousness after work				
Vocational factors manual workers separately				
Fatigue back				
Repetitive work				
Monotonous work	*			
Sitting (≤ 2 hours)				
Psychological factors				
MMPI test Hy scale				
Eysenck test Extroversion scale				
Social factors				
Tendency to report sick				
Contacts with social welfare authorities				
Demographic factors				
Age				*

Demographic factors

Age

Patients below 30 years of age tended to have a significantly longer initial episode of pain ($p < 0.05$) and longer absence from work during relapses in the year of observation ($p < 0.05$) compared to the age groups 30 to 50 years and above 50 years of age. The other course determining variables were not related to age.

Sex

No differences were observed between men and women as regards the duration of back pain and subsequent absence from work during one year.

Table 27 summarizes all the confounding factors found to be of significance in relation to the periods of pain and absence from work in one year.

Table 27 The confounding factors found to be related to the course of disease
*Definitions * = $p < 0.05$ ** = $p < 0.01$ *** = $p < 0.001$*

Confounding factors	Duration of initial episode	Duration of sick listing during initial episode	Duration of relapses	Duration of sick listing during relapses
History of back pain				
Onset of symptoms	*			
Pain index				
Initially		*		
After ten days	***	***		
Objective findings				
Pain on percussion		*		
Straight Leg Raising Test		**		

Table 27 continued

RESULTS PART III

EFFECTS OF THERAPY

Duration of symptoms in the treatment groups following the first treatment

A comparison of the duration of symptoms following the first treatment between the treatment groups was performed The influence of the time between onset of symptoms and first treatment (x) was eliminated by means of a covariance analysis with x as a concomitant variate The adjusted mean values of the time between first treatment and recovery (y) were compared Fig 19 The antilogarithms of the adjusted mean values were 14 8 days for the Back School group 15 8 days for the combined physiotherapy and 28 7 days for the placebo group The 95 % confidence interval for the difference between the combined physiotherapy group and the placebo group was 0 59 ± 0 37 No difference was detected between the Back School group and the combined physiotherapy group

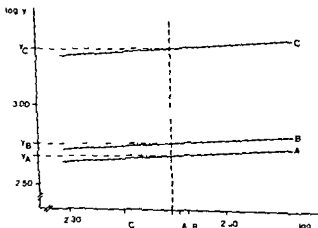


Fig 19 The regression lines of the time between first treatment and recovery (y) on the time between onset of symptoms and first treatment (x) of the groups Number of days in logarithms. $\bar{\bar{x}}$ = overall mean. A = Back School B = Combined physiotherapy C = Placebo

The change of pain during the initial episode

The change of pain and the degree of functional limitation in the treat ment groups are shown in Table 29 and Fig. 20 in terms of the pain in dex as described on page 28

Table 29 The change of pain during six weeks in the treatment groups by means of the median values of the pain index Range of scores for the pain index is 0 - 70 points. Group A = Back School, Group B = Combined physiotherapy Group C = Placebo Figures within parentheses indicate the number of patients examin ed on each occasion.

	Time of examination			
	Initial	10 days	3 weeks	6 weeks
Group A	43	20	19	22
	(70)	(44)	(25)	(14)
Group B	42	22	18	21
	(72)	(50)	(19)	(16)
Group C	42	28	25	17
	(74)	(56)	(32)	(15)

A similar decrease of pain was observed in all three groups from the in itial to the six week assessment. The mean difference in the pain index' per group was calculated by comparing the values from the initial assess- ment with the values from the ten-day and the three week assessments Table 30

Twentytwo patients were excluded from the analysis as they refused treatment. Four patients were initially randomly allocated to the physiotherapy group and 18 patients were allocated to the "placebo" group. Since a predominance of patients from the "placebo" group refused treatment, a separate comparison of the duration of the initial episode between the "placebo" patients and the non-treated patients was carried out. A chi square test did not reveal any differences between the two groups ($\chi^2 = 0.22$).

Duration of sick-leave during the initial episode of pain

A comparison was carried out between the number of non sick listed and sick-listed patients in each treatment group during the first episode of back pain. No significant difference was found between the groups.

The median duration of absence from work during the initial episode among the sick listed patients was 20.5 days in the Back School group, 26.5 days in the physiotherapy group and 26.5 days in the "placebo" group.

When the three groups were analyzed in relation to the total duration of absence from work (median 21 days) there were significantly more patients with a shorter duration of sick leave in the Back School group compared to the "placebo" group. Table 28.

Table 28. Sick leave during the initial episode of pain in the treatment groups. Group A = Back School. B = combined physiotherapy. C = "placebo".

	≤ 21	> 21 days	total
Group A	37	18	55
Group B	30	31	61
Group C	25	41	66

$\chi^2 = 10.44$, df = 2, $p < 0.01$

Table 30 Comparison of the mean difference of the pain index per group on three occasions of assessment Group A = Back School Group B = Combined physiotherapy Group C = Placebo

	Initial – 10 days $\bar{d}$	Initial – 3 weeks $\bar{d}$
Group A	15 10	15 21
Group B	19 22	17 20
Group C	12 52	17 53

When comparing the mean values of the Back School and physiotherapy groups with the mean value of the placebo group a similar mean decrease of pain was observed in all three groups on the two occasions of assessment following the initial assessment

Recurrences of pain in one year

Number of recurrences

The number of patients in each treatment group with no recurrences was compared with the number of patients with recurrences during one year 36 % of the patients in the Back School 40 % of those in the physiotherapy group and 29 % in the placebo group had no recurrences during one year No relation was found between the type of treatment given and the incidence of recurrences. The median number of recurrences in one year was 2 75 in the Back School group 2 75 in the physiotherapy group and 2 25 in the placebo group On comparison of the number of recurrences in the different groups no relation was found between the type of treatment given and the number of recurrences of pain

Total duration of recurrences of pain in one year

The median number of days of recurrences for the three groups together was 27 days. No significant differences were detected when comparing the total length of recurrences in days during one year in each group

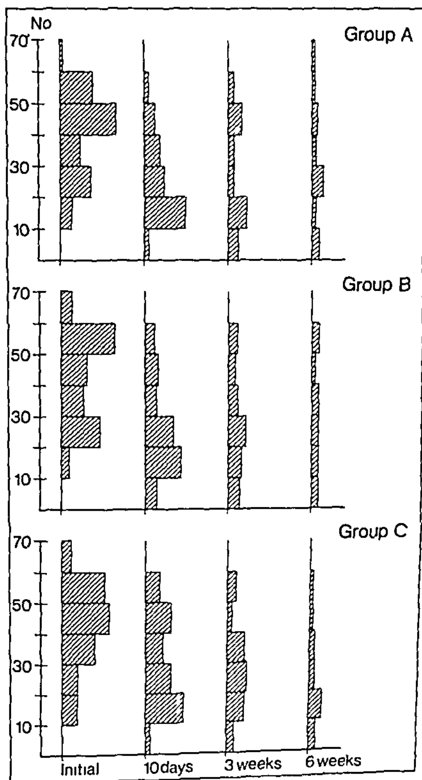


Fig 20 The change of pain in the treatment groups during six weeks as determined by means of the pain index The range of scores of the pain index is 0 – 70 points

DISCUSSION

GENERAL DISCUSSION

When interpreting the results of this study certain general limitations of clinical research of this type have to be considered

The requirement of blindness in this type of a study is difficult to fulfill when the patients are aware of what treatment they are subjected to It is also difficult to guarantee that the patients do not reveal the treatment received to the assessing physician In a study by Doran and Newell (1975) it was found that the assessing physician inadvertently discovered the treatment in 10 % of the cases No systematic control of the number of patients reporting their treatment was carried out in this study

The reliability of information obtained from the patient has been investigated by Westrin et al (1972) They came to the conclusion that the information could be influenced by the investigator as well as by the investigated individual

The validity of diagnoses of low back pain may also be questioned in view of the lack of knowledge regarding the pathophysiology of low back disorders In this study an attempt was made to achieve homogeneity of diagnosis in the studied group by only including patients with 1) pain in the lumbar region with or without sciatica to the thigh 2) a duration of symptoms not exceeding three months, 3) a pain free year preceding the current episode

However nothing can be said with certainty about the homogeneity of the underlying causes of the pain in the studied group

The lack of knowledge about the etiology of back pain also makes it difficult to find objective methods of assessing clinical manifestations Thus the clinical methods available for measuring the mobility of the spine or the strength of certain muscles lack normal value Furthermore when pain is present the difficulties in obtaining objective values increase since the methods for registering pain are inadequate Hence at an examination the investigator obtains the patient s own assessment of pain intensity and functional limitation rather than measures of mobility and strength

Total duration of absence from work in one year owing to recurrences

The number of patients not reporting sick during relapses was compared to the number of patients who were sick listed in the different treatment groups 51 % of the patients in the Back School, 49 % of those in the physiotherapy group and 46 % of the "placebo" group were not absent from work during one year because of recurrences The median number of days of sick leave owing to recurrences in one year was 7 5 days in the Back School group, 7 5 days in physiotherapy group and 8 days in the "placebo" group No significant differences were found between the groups

Development of chronicity rhizopathy, and lumbar insufficiency

The distribution of patients developing chronic pain, rhizopathy and lumbar insufficiency in the three treatment groups is demonstrated in Table 31

Table 31 Development of chronic pain rhizopathy and lumbar insufficiency

	Group A	Group B	Group C	Total
Chronicity	4	4	2	10
Rhizopathy	5	7	6	18
Lumbar insufficiency	44	46	45	135

Change of occupation

More than half of the 217 patients changed their jobs during the year of observation More patients changed jobs in the "placebo" group (61 %) compared to the Back School patients and the physiotherapy group (50 %, 46 %) Also the patients changed their jobs because of back pain more frequently in the "placebo" group (27 %) than in the other treat ment groups (10 %, 14 %)

The median age of the patients was 34 5 years which agrees fairly well with what is known about the age distribution of back pain in the general population (Hult 1954 Hirsch et al 1969, Horal 1969 Kelsey 1975) Back pain is known to be about equally common in men and women (Horal 1969, Kelsey 1975) In this study 13 % of the patients were women while 20 % of the employees at Volvo are women The design of the study does not admit prevalence analyses however

The median duration of symptoms before entry of the patients to the study was only 9 days and 43 % of the patients had never had any episodes of back pain before This is a consequence of the efforts to include only acute and subacute cases without a tendency to chronicity Anamnestic statements on history of back pain have been shown to be subject to uncertainty however and the history is often more extensive than the patient has reported (Westrin et al 1972)

Almost half of the patients had a sudden onset of pain often in connection with a specific incident an observation that is in agreement with several other reports (Seager 1959 Glover 1960) Lifting and bending manoevres have often attracted interest as provoking factors In this study they were reported in connection with onset of back pain in about 15 % each and were the most common provoking factors Hult (1954) found that 15 – 20 % of lumbago patients reported onset of symptoms in connection with lifting. In the present study onset of symptoms occurred slightly more frequently during leisure time than during workinghours

The subjective symptoms were penetrated by means of questions about the intensity and character of the pain and consequent functional limitation The questions regarding pain intensity were similar to those used by Horal (1969) In the present series 67 % of the patients thought that their pain was intense while 84 % of the probands in Horal s study had experienced intense pain in their backs on some occasion This indicates that the patients in the present study had a severity of pain that at least corresponded to an ' average episode of lumbago This is also supported by the fact that about half of the patients had continuous pain through out the day and night which is similar to what Horal has reported for the probands in his study The functional limitation was studied by 10 questions with 4 alternative answers to each The three most common alternatives among the 40 statements describing functional limitation were (Table 12) 1 Participation in sports impossible (85 %) 2 Bending

An investigation of a multifactorial disorder like low back pain may be characterized by an abundance of soft variables the influence of which is not always easy to determine

PATIENT PROFILE

In this part of the report the distribution of demographic, clinical, vocational, psychological and social factors among the patients is presented The sources of data contributing to the patient profile are of different kinds Three classes of information, with different modes of collecting and differing reliability, can be distinguished

1 Patients' own statements

a with undoubtedly good reliability
This class comprises information about age and certain checkable and unequivocal vocational data such as category of employment and the occurrence of shiftwork

b With unknown reliability
The majority of data making up the patient profile are of this kind This includes information about the history of back pain, mechanism of onset the condition of pain, certain social and vocational factors and also results of the psychological tests This type of information can be influenced by errors characterizing either the investigator or the investigated individuals themselves (Westrin et al , 1972)

2 Clinical findings

Objective clinical findings are subject to the investigators judgement and measurement There is a certain amount of error involved in registering the clinical findings, but as this has been done by one investigator only in this study, the shortcomings will tend to be uniformly distributed

3 Information from authorities

Information has been obtained from the National Health Insurance Office and from the social welfare authorities Information from the former has good reliability Information from the latter has good reliability regarding the presence of the studied factors among those who have been registered by the authority, but not regarding the absence of these factors among those who have not been registered

at Volvo are manual workers The design of the study does not permit any conclusions about the frequency of low back pain among different categories of employees in industry but it is interesting that this slight overrepresentation of manual workers is in good agreement with several reports about the occurrence of low back pain in different occupations (Hult 1954 Rowe 1969) The length of employment for the patients was fairly long 72 % had been employed for more than three years and only 4 % had been employed for less than 1 year Since we do not know whether the patients in the material are representative of all Volvo em ployees with back pain we cannot draw any conclusions about the length of employment and occurrence of back pain on the basis of these figures, but Magora (1970) found a positive relation between years of employ ment and frequency of back pain Without drawing any firm conclusions it is also interesting that shift work was not more common among the patients than among all manual workers at Volvo

Manual workers were subjected to a greater strain from an ergonomic point of view with frequent bending and twisting movements less vari ation and consequently more back fatigue than the office staff On the other hand the level of satisfaction with the vocational situation seemed to be about equal for both categories of employees

Data describing social conditions were obtained partly from question naires and partly from authorities The reliability of these two types of information has been briefly discussed earlier The questionnaires pene trated basic family circumstances psychosomatic symptoms and also the patients habits as regards physical exercise Although these questions only give a superficial picture of social conditions they indicated normal family conditions for the majority of the patients Psychosomatic symp- toms occurred infrequently Half of the patients took part in physical exercise Contact with the social authorities since 1974 could be estab- lished for 12 % of the patients. The average total duration of sick leave under various diagnoses was 15 5 days per year for the last two years be fore entry to the study This is less than the average for industrial work ers in Göteborg (NHIO-statistics) With the reservation that answers to questionnaires and the absence of contact with social authorities does not exclude social problems the findings indicate that social problems were not prominent in this study In several other investigations on back pain (Natvig 1970 Westrin 1970 Helander 1973) a lot of social prob-

forwards painful, but could be done (80 %) 3 Sitting painful, but not impossible (73 %) That the sitting posture is so frequently considered painful is consistent with knowledge of the biomechanical loads on the spine in different postures (Nachemson & Elfstrom 1970)

The frequency of a positive SLR test is partly a question of definition In this study a positive SLR-test was defined as pain in the back, when the straight leg was raised With this definition 62 % of the patients had a positive SLR test but only 14 % of the patients had a positive SLR test below 60 degrees Magora (1975) reported a positive SLR test in 20 % of the patients with low back pain

The range of spinal flexion, extension and lateral flexion was evaluated by objective methods in the sense that the investigator estimated the range of movements by measurements between defined points Moll and Wright (1971) have confirmed the validity of these methods Rotation was estimated by a method where by the deviation of a plane through the shoulders from an imaginary zero line was measured with a gonio meter This method cannot be considered completely objective The mean values in this study for lumbar extension and lateral flexion were in close correspondence to the mean values that Moll and Wright (1971) have re ported for a normal male population of 35 years of age The mean value for lumbar flexion was lower than the mean value in that normal popu lation, however This is probably a consequence of the fact that 89 % of the patients had increased pain on flexion, while provocation of pain oc curred less frequently in the other planes of movements In fact, aggra vation of pain on lumbar flexion was the most common clinical finding Pain on palpation and percussion was reported by 60 % and 39 % respec tively, while postural scoliosis and muscle spasm occurred in less than 20 %

Data describing vocational factors consist partly of unequivocal infor mation e g category of employment shift work and length of employ ment Information about ergonomic load has been obtained from ques tionnaires and is not based on objective measurements This method with similar questions has previously been used by Magora (1972, 1973) in an extensive study Finally there is purely subjective information about the patients satisfaction with their jobs and their opinions about the physical and psychological strain in their work The proportion of manual workers among the patients was 73 % while 65 % of all employees

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lems have been present The present study and the studies referred to deal probably with populations of back pain patients that are somewhat different The previous studies include chronic cases, while only acute and subacute cases were included in the present study Furthermore, as this study was performed at a factory only patients who were permanent ly employed were included

There are several reports in the literature about the use of the MMPI for evaluation of psychological factors associated with back pain (Hanvik 1950 Beals & Hickman 1972, Sternbach et al 1973, Timmermans & Sternbach 1974, Wiltse & Rocchio 1975) In groups of patients with long standing back pain the Hs and Hy scales seem to be regularly elevated in comparison with normal individuals Furthermore, back pain patients have been found to have higher values on these scales than other patients with pain and functional limitation, e g fracture patients and patients with rheumatoid arthritis (Phillips 1964, Beals & Hickman 1972, Stern bach et al 1973) In the present study the Hs and Hy-scales of the MMPI were modified for Swedish conditions by exclusion of some questions The scores on the Hs scale were normally distributed, while the scores on the Hy scale were shifted towards the lower end of the scale Since there is little experience of this test in Sweden, and consequently a lack of adequate reference values and since the scales were modified, no com parisons have been made of the distribution of the scales in this study with that in normal populations The scales were only used to distinguish between different groups of patients who were compared with regard to the course of the disease This will be discussed below There are no re ports in the literature about the distribution of the scales of the Eysenck test among patients with back pain but the test has been used for several years in Sweden in psychological practice In this study the Extroversion scale was normally distributed, while the Neuroticism scale was shifted towards the lower end of the scale The distribution of the scales does not differ from the distribution in a normal population (Bederoff Pe tersson et al 1968)

COURSE OF THE DISEASE DURING 1 YEAR

At the follow up examinations the patients reported whether they had recovered or not, and if they had recovered, they were asked to try to

state on what date the recovery had occurred The patients were classified as having recovered when they did not have pain every day evoked by normal every day exertion If they only had stiffness or fatigue in the back or pain evoked only by extraordinary exertion they were defined as having recovered but as having symptoms of lumbar insufficiency This demarcation gives some uncertainty as the results might be influenced both by the patient s statements and by the investigator's judgement Since there was only one investigator in the study any errors of judgement will tend to be uniformly distributed among the patients

35 % of the patients recovered within one month 70 % within 2 months and 86 % within three months 6 % had a duration of pain longer than 6 months The recovery rate within 1 month is a little low in comparison with several other reports (Horal 1969 Nachemsson 1976) This might be explained by the fact that only a minority of patients with very short duration were included in this study The recovery rate at two months and later is in fairly good correspondence to that in other reports (Horal 1969 Nachemsson 1976)

The information about sick listing during the initial episode and during relapses has been checked with the National Health Insurance Office 85 % of the patients were sick listed during the initial episode but the duration of sick leave was considerably shorter than the period of pain There was a significant relation ($p < 0\ 001$) between the duration of pain and duration of sick listing during the initial episode however When studying sick listing it is important to remember that it does not solely reflect the severity of the condition It is also influenced by various vocational social and personality related factors

The patient s description of pain location was mapped and coded by the investigator The distribution of pain location among the patients on the different occasions of investigation showed a remarkable uniformity within the group during 6 weeks The only divergence was a slight increase in radiation of pain at 6 weeks which may be a consequence of the fact that 8 % of the patients developed rhizopathy during the year of observation

The pain index is the sum of scores for several indices of pain and functional limitation The more severe the patient s description of the pain was the higher was the pain index Median values for the pain index at the initial examination were compared with median values for the pain

index at the subsequent investigations There was a reduction of the pain index by 50 % between the initial examination and the 10 days examination, after which the pain index remained almost stable at the following two examinations It is uncertain whether the change during the first 10 day period represents a true change in the patient s condition or an altered attitude to the questions concerning pain, or a combination of these two factors

After recovery from the first episode, the patients were followed up by further examinations and asked about relapses. 62 % had one or more relapses, and 18 % had more than two relapses On an average, the reported relapses were more benign in character than the initial episode When the relapses for each patient were totalled the median duration was 27 days, which is one week less than the median duration for the initial episode 50 % of the patients with relapses were sick listed, while 85 % of the patients were sick listed during the initial episode

62 % of the patients had symptoms of lumbar insufficiency either in connection with recovery from the initial episode or later Hult (1954) reported that 26 % of a group of patients with low back pain also had symptoms of lumbar insufficiency The discrepancy in the incidence of insufficiency in the two studies might be explained by the prospective nature of the present study A prospective study allows better possibilities of detecting even transient episodes of back pain and slight symptoms of lumbar insufficiency Since there are very few prospective studies on low back pain in the literature, the results of the present study are not directly comparable with those of other studies

INFLUENCE OF CONFOUNDING FACTORS ON COURSE OF DISEASE

Many of the factors contributing to the patients profile were related to the course of the disease

History of back pain

Patients without previous episodes of back pain had a shorter duration of recurrences than patients with up to three previous episodes ($p < 0.05$) On the other hand, the 15 patients who had more than 3 previous episodes tended to have a shorter duration of recurrences than patients without previous episodes of back pain This relationship is very uncertain due to the small number of patients but it makes it difficult to draw conclusions about the influence of previous episodes on recurrences

Patients with an insidious onset of symptoms had a longer duration of the initial episode than patients with a sudden onset ($p < 0.05$). The relation was rather weak and cannot be considered conclusive, but might be an indication that back pain with different types of onset is in some respect different. No answer to this question has been found in the literature.

Clinical findings

The severity of symptoms at the initial examination, expressed by the pain index, was related to the duration of sick leave ($p < 0.05$), but not to the duration of pain. When those patients who still had severe symptoms, expressed by a high pain index, after 10 days, were analysed separately, there was a stronger relation to the duration of sick leave ($p < 0.001$) and also a relation to the duration of the initial episode of pain ($p < 0.001$). Thus, the intensity of the patients' pain at the first visit is no indication of the duration of pain. On the other hand, if severe symptoms have not subsided within 10 days, the duration of the episode will probably be prolonged. Quite logically, sick listing occurred more frequently if the symptoms were severe.

When other clinical manifestations, such as radiation of pain to the thigh, decreased lumbar flexion, the presence of postural scoliosis, the presence of pain on percussion and a positive SLR test, were related to the course of the disease, it was found that none of them had any influence on the duration of the episode. Neither did any of them affect the length of relapses. The only relationship found was that both patients with a positive SLR test and those with pain on percussion had a longer duration of sick leave during the initial episode ($p < 0.01$). Consequently, in this study, patients with severe symptoms and certain clinical findings had a longer duration of sick leave, but these circumstances did not affect the duration of symptoms or the tendency to relapse. On the other hand, if the patients had severe symptoms and these did not subside within 10 days, the duration of symptoms was significantly prolonged.

Vocational factors

The influence of vocational factors on the course of acute low back pain may be interpreted in terms of more or less strong relations to the prognosis of the disorder. The pronounced differences in the course of the disease between the office staff and the manual workers must be of de

cisive importance when evaluating the relation between vocational factors and the duration of back symptoms and any consequent absence from work

There are probably other possible explanations apart from vocational differences for the significantly shorter duration of the initial episode and the shorter absence from work among the office staff compared to the manual workers

However, the vocational factors related to significantly longer duration of symptoms and absence from work were so highly associated with the working conditions of manual workers only that these vocational factors can not be excluded as having played a part in causing the differences observed between the two categories

Owing to the skewed distributions of vocational conditions and consequent lack of analyses, it is impossible to establish the magnitude of the influence of all the vocational factors on the course of low back pain

Job satisfaction, bending and twisting could not be analysed in relation to each category of employment and the duration of back symptoms

Fixed postures, lifting and forceful movements together with a low requirement of concentration and exhaustion after work were all related to either a prolonged duration of symptoms or absence from work or both in the analysis of the whole population These relations were not observed in the separate analysis of manual workers only There is there fore, no evidence of a strong relation between these variables and the course of acute low back pain among manual workers These latterly mentioned working conditions were not common enough in the office staff to be analysed separately

For the same reason, daily back fatigue, repetitive and monotonous work could not be related to the course of disease in the office staff only However daily back fatigue and repetitive and monotonous work were still significantly related to a longer duration of the initial episode in the separate analysis of manual workers Moreover sitting for less than two hours per day was associated with a prolonged absence from work during the initial episode This prolonged absence from work cannot be explained only by the fact that the patients sat rarely since the patients who stated that they sat for less than two hours per day at the same time reported that their work required standing bending and twisting postures

most part of the day These vocational circumstances could also explain the prolonged absence from work.

Since the vocational factors studied are strongly related to each other, the results of this study do not reveal which vocational factor or factors are of greatest importance for determining the course of acute low back pain The results only emphasize the need for further investigations in this field

Psychological factors

In the present study the patients filled in a psychological inventory com prising a modification of the Hs and Hy scales from the MMPI test be fore treatment was begun Six months after entering the study the Eysenck test was administered to the patients A relation was found be tween a high score on the modified Hy scale and a longer duration of the initial episode and also to a longer duration of sick leave during the initial episode ($p < 0.05$) The Hs scale showed no relation to the course of the disease A low score on the Extroversion scale of the Eysenck test was associated with a longer duration of relapses ($p < 0.05$) while the Neuroticism scale of this test was not related to the course of the disease It is quite logical that the Extroversion scale of the Eysenck test was re lated to the duration of relapses and not to the duration of the initial episode since this test was administered to the patients 6 months after their entry to the study

The relations found are weaker than in several of the studies on the pre dictive capacity of the MMPI (Beals & Hickman 1972 Wiltling et al 1973 Wiltse & Rocchio 1975) and cannot be considered conclusive In the pre vious studies most of the patients had more longstanding back pain than the patients in the present study and they may differ in respect of the importance of psychological factors Furthermore the treatment methods were different and the scales of the MMPI that have been used in this study are not identical with the ordinary scales

Although the relationships that have been found are not conclusive they do indicate that psychological conditions may be of importance even in acute cases To get a definite answer to this and to elucidate to what ex tent psychological factors are important further investigation is necess ary

Social factors

As previously mentioned, there are several reports in the literature of an association between back pain and social problems of different kinds (Natvig 1970, Westrin 1970, Helander 1973), but there are few studies that relate these problems to the result of treatment of back pain Ros lund (1974) found that the result of surgical treatment for herniated disc was related to the occurrence of *preoperative social problems In this* study the minority of patients that had a documented contact with the social welfare authorities had a longer duration of the initial episode ($p < 0.01$) The contact with the social welfare authorities mainly took place during the period of the study This means that it is uncertain whether the relation is an indication that patients with social problems tend to have a poorer prognosis or that patients with longstanding back pain gets social problems Irrespective of the origin of the relation patients with a manifest need for *support from the social welfare authorities were sig* nificantly more often found among patients with longstanding back pain Considering this fact, it is a little surprising that the occurrence of con tact with the social welfare authorities did not influence the duration of sick leave during the initial episode However in this study the reason for contact with the social welfare authorities has in most cases been con stant financial problems which might have influenced these patients to cut their sick leave as short as possible

Previous psycho somatic symptoms

Patients who had reported "psychosomatic" symptoms of different kinds did not differ from patients without these symptoms as regards the course of the disease This may be compared with Westrin's (1970) *findings that psychiatric symptoms were* not more common among pa tients who had been sick listed for back pain than among controls

Tendency to report sick

Patients with a high rate of sick-listing under various diagnoses during the two years before entry to the study also had a longer duration of sick leave during the initial episode ($p < 0.001$) The duration of pain was not longer for these patients however Consequently, patients with an exten sive history of sick leave under various diagnoses had a greater tendency to be sick-listed during the episodes of back pain This is in agreement with the findings of Westrin (1970)

Demographic factors

In this study young patients had a longer duration of the initial episode ($p < 0.05$) and were more often sick listed during relapses than older patients ($p < 0.05$) This is contrary to other reports (Horal 1969 Haber 1971 Wood & Leish 1974) in which older patients have a more prolonged disability The findings regarding the influence of age in this study are probably indirect however and can be explained by the fact that while the median age in the total material is 35 years the median age among the office staff who in this study proved to have a more benign course is 42 5 years

There was no difference between the sexes in respect of the course of the disease This is in contrast to the findings of Leavitt et al (1971), who reported a poorer prognosis for women in a study on industrial back injury

The results indicate that clinical findings both subjective symptoms and objective findings are of little prognostic value when determining the course of acute low back pain On the other hand the results indicate that certain vocational psychological and social factors are more important when determining the course However the magnitude of the prognostic importance of these factors is not possible to establish from the results in this study

EFFECTS OF THERAPY

Low back pain is often described as periodic in nature with spontaneous remissions (Rowe 1969) The natural history of the disorder must therefore be considered when evaluating therapeutic effects

This investigation showed that 70 % of the studied group recovered from the initial episode within two months and 86 % within three months regardless of the treatment given These figures correspond fairly well with observations by others (Hult 1954 Horal 1969)

The significantly shorter duration of symptoms following the Back School treatment and combined physiotherapy in *relation to placebo* treatment is thus worthy of attention

Pronounced differences were observed between the group given "placebo" and the two groups given Back School and physiotherapy treatment when using the time following the first treatment as the effect variable

It was therefore of interest to see whether the differences in the duration of symptoms after the first treatment could be explained by corresponding differences in time between the onset of symptoms and first treatment in the treatment groups

The results indicate that the treatment groups did not differ significantly in time for applied treatment in relation to onset of symptoms There is, moreover a marginal trend indicating that the longer the time elapsing between the onset of symptoms and the start of therapy the longer the time taken after the first treatment until recovery This observation is evidenced by the *inclination of the lines in Fig 19 on page 73*

The results of the analysis indicate that, with Back School treatment or combined *physiotherapy of the type described in this study*, patients with acute low back pain recover faster the earlier therapy is instituted

However, the results do not reveal what kind of effect the two modes of therapy have as compared to the "placebo" alternative Since very little is known about the causes of back pain and therefore about the specific effect of therapy, there is reason to expect as pronounced a placebo effect in the Back School and physiotherapy groups as in the "placebo" group

The magnitude of the placebo effect is *difficult to* measure with present methods The personality of the patient and of the therapist and the time spent with the therapist are probably important *factors* when one is trying to assess the placebo effect

The significant effect of the Back School in *relation to the 'placebo'* group might to some extent be explained by the fact that the patients spend more time with the therapist in the Back School In both groups the patients are not actively treated and they should therefore be reasonably comparable

The Back School and the combined physiotherapy *are more comparable* as regards the time spent with the therapist This could be one explanation why there is so little difference in treatment results between the Back School and the combined physiotherapy *Physiotherapy as defined*

Variations in placebo effect, in compliance and in distributions must also be considered when evaluating absence from work The possibility of skewed distribution of the studied confounding factors is eliminated according to the tables in the appendix mentioned above

The placebo effect and the variation in compliance are factors included, on the other hand, in the significantly shorter absence for the Back School patients This is perhaps not a surprising result since one of the main aims of the Back School is to teach the patients how to work in pain free postures when the condition of the back so permits

The reason for using variables related to recurrences as effect variables was to investigate whether preventive measures in the form of the Back School influenced the incidence and length of relapses or consequent absence from work in relation to the other groups Such an effect was not confirmed by the results, which showed a lack of difference between the three groups A possible effect may, however, be masked by the fact that the patients may have received treatment during recurrences

All the effect variables mentioned so far are quantitative in nature An attempt was also made to compare the treatment groups qualitatively by investigating whether a more pronounced relief of pain could be observed during the course of the initial episode in the studied groups

The corresponding median values and mean differences in the groups do not indicate that any of the three therapies are symptomatically superior to the others

The fact that the patients in the "placebo group changed occupation because of their back disorders more often than the Back School and physiotherapy patients was a finding which can be subjected to speculative explanations only Consequently the differences obtained between the treatment groups in the frequency of changing occupation will not be discussed any further

At the present stage of research there is a lack of methods for establishing a physiological relationship between the therapy given and the reduction of clinical manifestations. Moreover, the magnitude of a possible placebo effect of therapy on low back pain is unknown

Pending more research in this field the effect of the Back School and combined physiotherapy should be evaluated with reference to the time and expenses involved in the treatment of low back disorders

on p 31-37 in this study is to a great extent directed towards manual con tact with the patient This might also contribute to a further placebo ef fect. There are other reasons to speculate on the role of the time spent with the therapist. There was no significant difference in duration of the initial episode between the non treated patients and the placebo group These two groups spend equally short time with the therapist compared to the Back School and physiotherapy patients who spend equally long time with the therapist

Variation in compliance i e the patient s ability and will to comply with directions given is a factor that is as difficult as the placebo effect itself The Back School consists exclusively of lectures. The effect of the School must therefore be seen in relation to the patient's compliance with in structions given

No specific investigation of compliance was carried out in this study owing to the unsatisfactory nature of the methods available It is poss ible to determine the retention of theoretical knowledge obtained in the school but this gives no information about the ability of the patients to follow the practical instructions given

The patient s subjective opinion of the value of the Back School has been presented in a study by Lidstrom & Zachrisson (1973) 75 % of the pa tients reported positive experience of the School

The short duration of symptoms following Back School treatment and physiotherapy in relation to placebo must also be elucidated with ref erence to the previously discussed confounding factors To avoid unde sired effects of the confounding factors in the treatment groups there are several approaches that may be used One is to stratify according to factors known to influence the disorder studied Others (Magora 1970 Sternbach et al. 1973) indicate that vocational and psychological fac tors are of importance and they were therefore chosen for the stratifi cation in this study Another way to obtain an equal distribution is to study a sufficiently large group The appendix indicates the distribution of confounding factors in the treatment groups. It will be seen that the distribution is equal Thus the difference in the duration of symptoms following the first treatment in the three groups cannot simply be ex plained by a skewed distribution of the confounding factors which per se might influence the results

Variations in placebo effect, in compliance and in distributions must al so be considered when evaluating absence from work The possibility of skewed distribution of the studied confounding factors is eliminated ac cording to the tables in the appendix mentioned above

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At the present stage of research there is a lack of methods for establish ing a physiological relationship between the therapy given and the reduc tion of clinical manifestations. Moreover the magnitude of a possible placebo effect of therapy on low back pain is unknown

Pending more research in this field, the effect of the Back School and combined physiotherapy should be evaluated with reference to the time and expenses involved in the treatment of low back disorders

The duration of symptoms following the first treatment did not differ significantly in the two treatment groups In addition, the significantly shorter absence from work was observed among the Back School patients

With these findings in mind, there is reason to discuss the demands on resources made by the Back School as compared to combined physiotherapy

The possibility with the Back School of treating several patients at each lesson is the most obvious advantage over combined physiotherapy which allows only one patient per treatment session

The additional effect of the Back School on the absence from work also favours the use of the Back School system

Judging from the evidence found in this study relatively small resources in the form of the Back School are sufficient to achieve the same results as therapy requiring more time and personnel.

SUMMARY AND CONCLUSIONS

The aims of this investigation were

1 to describe a population of patients with acute and subacute low back pain The patients had to meet the following criteria

   a. lumbo-sacral pain with or without radiation to the thigh

   b duration of pain before entry to the trial not longer than three months.

   c a pain free year before the onset of the current episode

2 to determine whether various clinical vocational psychological and social factors are of any prognostic value when assessing the course of acute and subacute low back pain,

3 to evaluate the effect of

   a. the Back School based on ergonomic advice

   b combined physiotherapy consisting of mainly manual therapy

   c placebo' by means of low intensity short wave diathermy

   on acute and subacute low back pain

This prospective investigation was carried out at the Medical Department of the Automotive Division of AB Volvo Göteborg Sweden

Of all patients consulting the Medical Department because of low back pain from August 1974 to May 1975 217 fulfilled the criteria for ad mission to the trial These patients were all followed for one year No drop-outs were registered

The patients underwent a clinical examination and completed a question naire about previous back symptoms current symptoms and their social and vocational situation The patients also underwent psychological tests comprising the Hs and Hy scales of the MMPI The patients were then randomly allocated on the basis of the psychological tests and vocation

al factors, to one of the two treatments or to the "placebo" group given low intensity short wave treatment After the completion of treatment, the course of the disease was registered at 5 – 7 fixed control examinations during one year During this period information was also collected from the social welfare authorities and the National Health Insurance Office The patients were also subjected to a further psychological test, the Eysenck Personality Inventory, six months after entry to the study

The average age of the patients was 34 5 years and 13 % were women, as compared to 20 % women among all Volvo's employees in Goteborg Just over half the patients had previously suffered from back symptoms in the form of one or more attacks of lumbago or sciatica The duration of the current episode of pain when the patients first attended the medical centre varied between one and 86 days, with a median duration of 9 days Just over half the patients had a gradual onset of symptoms while the remainder had a sudden onset, often in connection with lifting or bending

All patients had low back pain 26 % had radiation of the pain to the gluteal region or thigh A majority of the patients considered their pain to be intense and half had continuous aching Coughing and sneezing caused aggravation of the pain in 40 % Pain when leaning forward and sitting was the predominating functional limitation

Straight Leg Raising Test was positive in 62 % of the patients, while only 14 % had a positive test below 60° Almost 90 % of the patients had pain on lumbar flexion, and the mean value for flexion according to a modification of Schober s method was lower than normal The mean values for extension and lateral flexion were within the normal limits and a minority of the patients experienced pain during these movements Pain on percussion was noted *in 40 % and tenderness on palpation in 60 % of the* patients Less than 20 % of the patients had a postural scoliosis or pronounced muscle spasm

27 % of the patients were office staff, which means that they were only slightly under represented compared to the proportion of office staff among Volvo s employees Sitting predominated as the working posture among office workers and standing among manual workers A minority of both categories of employees considered that their working posture was completely fixed during most of their working day Bending and twisting movements during work were reported by the majority of the

manual workers, whereas lifting and forceful movements were less com mon A majority of both categories of employees considered that their work required concentration during at least part of the day whereas variation in the work occurred more frequently among office staff A majority of the patients considered their work not to be particularly fa tiguing. Most of the patients were satisfied with their jobs and with their working environment 75 % of the patients had been employed at Volvo for more than 3 years

Of the 217 patients 12 % had had contacts with the social welfare auth orities since 1974 owing to financial problems problems in adjusting or alcoholism Psychosomatic symptoms were infrequent. The total duration of sick leave during two years before the study was lower than the aver age for industrial workers.

The distribution of personality variables in the Eysenck test accorded with the distribution in a normal population The hysteria and hypo-chondriasis scales of the MMPI showed low distributions but no com parison with other populations has been carried out.

The episodes of pain lasted less than one month in 35 % and less than 3 months in 87 % of the patients while 4 % of the patients still had pain after one year The median duration of pain was 35 days During the initial episode of pain 86 % of the patients were sick listed with a median duration of sick leave of 21 days The location of the pain did not alter during the first 6 weeks except that there was a slight increase in the number of cases of radiation of pain at the end of this period The inten sity of pain decreased markedly during the first few weeks after which it remained relatively constant during the following month in those pa tients who still had symptoms. Just over 60 % of the patients had a re currence during the first year the mean number of recurrences being 1 3 per patient The recurrences were generally less severe and the median total duration of recurrences was 28 days 50 % of the patients with re currences were sick listed the median duration of sick leave being 16 days

Symptoms of lumbar insufficiency occurred during the follow up period in 60 % of the patients while 8 % of the patients developed rhizopathy

The history of back pain the clinical manifestations and the vocational psychological social and demographic factors characterizing the group

of patients studied were all related to the course of acute low back pain during one year The course of back pain has been characterized by 1) the duration of symptoms during the initial episode of pain, 2) the duration of sick leave during the initial episode, 3) the total length of recurrences of pain in one year and 4) the total duration of absence from work due to recurrences in one year

The number of previous episodes characterizing the history of pain was related to the course of low back pain The duration of recurrences was longer among those patients who had reported up to three previous episodes of pain compared to patients with no previous episodes However, this relationship was not observed among the patients who had had more than three previous episodes of pain These findings indicate that the number of previous episodes of back pain does not play an important part in determining the course of acute low back pain

Patients who reported an insidious onset of pain had a longer duration of the initial episode of pain than the patients who had a sudden onset Back pain may therefore vary in some respect depending on the type of onset

The severity of pain was expressed by a "pain index" based on several questions regarding pain The scores for the "pain index" on the various occasions of examination were related to the course of back pain A longer duration of sick leave was observed among the patients who had a high "pain index" score at the initial examination while the duration of pain initially was not influenced Patients who at the ten day examination still had an elevated "pain index" score were found to have both a prolonged initial episode and longer absence from work Severe pain mainly predisposes to prolonged sick leave

Other clinical manifestations such as radiation of pain to the thigh decreased lumbar flexion, the presence of postural scoliosis, the occurrence of pain on percussion and a positive SLR test, were not related to the duration of any of the episodes of pain in one year The only relationship found was a longer duration of sick leave among patients who had a positive SLR test and pain on percussion A positive SLR test and pain on percussion may also be regarded as an expression of pain intensity Consequently, patients with severe symptoms, in terms of both a pain index ' and certain clinical findings have a longer duration of sick leave

while the duration of the episodes of pain are not influenced unless the severe symptoms persist.

Vocational factors in terms of working postures required, vocational fatigue variation, satisfaction and need to concentrate at work, were related to the course of acute low back pain Frequent bending and twisting fixed postures lifting and forceful movements general fatigue, daily back fatigue repetitive work, no needs of concentration and discontent at work, were all related to either a longer initial episode of pain or a longer absence from work or both when all the patients were analysed together

A comparison between manual workers and office staff revealed pronounced differences in the duration of symptoms and sick leave in the two groups The manual workers had both a longer initial episode of pain and a longer duration of sick leave during both the initial episode and the relapses

Separate analyses of manual workers and office staff were then performed to determine whether the same relationships were observed between the vocational factors and the course of low back pain as in the analysis of the whole group of 217 patients. However working conditions differed so much between the two groups of employees that the separate analyses did not justify any firm conclusions as to which vocational factor or factors are of the greatest prognostic importance for determining the course of acute low back pain

Patients with high values on the Hy scale in the MMPI had longer episodes of pain and a longer duration of sick leave than other patients while the Hs scale showed no relation to the course of the disease Patients with low values on the Extroversion scale in the Eysenck test had a longer total duration of recurrences during one year than those with high values while the Neuroticism scale was not related to the course of the disease The findings support previous observations that psychological factors are of importance for the course of back pain No firm conclusions about the importance of psychological factors or the mechanism of the causal association can be drawn from the results of this study however

Patients who had had contacts with the social welfare authorities had a longer initial episode of pain than other patients This finding accords with previous reports of an association between pronounced back symp toms and social problems, but no conclusions can be drawn as to whether the social problems are a result or a contributory cause of the prolonged course

Patients who had previously had long periods of sick leave for different reasons showed a pronounced tendency to have a longer duration of sick leave during the current episode of pain The occurrence of certain psycho somatic symptoms was not related to the course of the disease The pa tients who regularly engaged in physical training did not differ from the other patients in respect of the course of the disease

The effect of three different methods of treatment on acute low back pain was evaluated The Back School was compared with combined physiotherapy and "placebo"

The effect of the treatments was estimated by relating the treatments to 1) the duration of symptoms following the first treatment, with special reference to the time elapsing from the onset of symptoms to the first treatment, 2) the length of absence from work during the initial episode, 3) the change of pain during the initial episode and 4) the number and length and duration of sick leave owing to recurrences of pain during one year

The time elapsing from the onset of back pain to the first treatment did not differ significantly in the three treatment groups

The duration of symptoms following the first treatment was 14 8 days for the Back School group 15 8 days for the physiotherapy group and 28 7 days for the "placebo" group

The patients attending the Back School were observed to have a shorter duration of sick leave during the initial episode than the other two treat ment groups The median absence from work was 20 5 days for the Back School patients 26 5 days for the physiotherapy group and 26 5 days for the "placebo" group The change of pain during the initial episode was equal in all the treatment groups Neither the number nor the length of absence from work owing to recurrences differed in the three treat-ment groups

Patients in the placebo group changed occupation more often because of back pain (27 %) than the physiotherapy (10 %) and the Back School patients (14 %)

There is enough evidence in this study to conclude that Back School and combined physiotherapy are superior to placebo treatment in acute low back pain The Back School program also reduces the absence from work.

The Back School, teaching several patients at a time must be regarded as an advantageous mode of therapy as relatively small recources are needed to achieve the same effects as with physiotherapy

REFERENCES

Andersson, B J G (1974) *On myoelectric back muscle activity and lumbar disc pressure in sitting postures* Thesis, University of Goteborg

Anderson, J A D (1976) Back pain in industry *The Lumbar Spine and Back Pain* Ed M Jayson, Pitman Med Publ Co Ltd

Arnoldi, C C (1972) Intravertebral pressures in patients with lumbar pain *Acta Orthop Scand* 43, 109–117

Badgley, C E & Arbor, A (1941) The articular facets in relation to low-back pain and sciatic radiation *J Bone Joint Surg* 23 2, 481–496

Beals, R K & Hickman, N W (1972) Industrial injuries of the back and extremities *J Bone Joint Surg* 54–A 8, 1593–1611

Bederoff-Petersson, Jagtoft, Åstrom (1968) *EPI Eysenck Personality Inventory Synpunkter och nagra svenska undersokningsdata* Upplaga 2, Skandinaviska Testforlaget AB

Bisla, R S , Marchisello, P J , Lockshin, M D , Hart, D M , Marcus, R E & Granda, J (1976) Auto immunological basis of disk degeneration *Clin Orthop* 121, 205–211

Bobechko, W P & Hirsch, C (1965) Auto-immune response to nucleus pulposus in the rabbit *J Bone Joint Surg* 47–B 3, 574–580

Chaffin, D B & Park, K S (1973) A longitudinal study of low back pain as associated with occupational weight lifting factors *Amer Industr Hyg Ass J* 34 12, 513–525

Chaffin D B (1974) Human strength capability and low back pain *J Occup Med* 16 4, 248–254

Cyriax, J (1959) *Textbook of Orthopaedic Medicine* Vol 2 Cassell London

Cyriax, J (1959) *Treatment by manipulation and massage* Cassell, London

Doran, D M L & Newell, D J (1975) Manipulation in treatment of low back pain A multicentre study *Brit Med J* 2 161–164

Forrest, A J & Wolkind, S N (1974) Masked depression in men with low back pain *Rheumatol Rehabil* 13 148–153

Freeman C Calsyn D & Louks J (1976) The use of the Minnesota multiphasic personality inventory with low back pain patients *J Clin Psychol* 32 2 294–298

Friberg, S & Hirsch C (1949) Anatomical and clinical studies on lumbar disc degeneration *Acta Orthop Scand* 19 222–242

Galante J O (1967) Tensile properties of the human lumbar annulus fibrosus *Acta Orthop Scand* Suppl 100

Gentry W D, Shows W D & Thomas M (1974) Chronic low back pain A psychological profile *Psychosomatics* 15 174–177

Gertzbein, S D Tile M, Gross A & Falk R (1975) Autoimmunity in degenerative disc disease of the lumbar spine *Orthop Clin North Am* 6 1 67–73

Glover J R (1960) Back pain and hyperaesthesia. *Lancet* May 1165–1169

Glover, J R, Morris J G & Khosla, T (1974) Back pain A randomized clinical trial of rotational manipulation of the trunk. *Brit J Industr Med* 31 59–64

Haber L.D (1971) Disabling effects of chronic disease and impairment. *J Chronic Dis* 24 469–487

Hansson T (1977) Microcalluses in trabeculae in lumbar vertebrae and their relations to bone mineral content *Spine* In press.

Hanvik L.J (1950) MMPI profiles in patients with low back pain *J Consult Psychol* 15 350–353

Hathaway S R & McKinsley J C (1967) *MMPI – Manual* The Psychological Corporation N Y Copyright University of Minnesota.

Helander E (1973) Ryggbesvar och arbetsoförmåga. *Socialmed T* 50 398–404

Hirsch C (1966) Etiology and pathogenesis of low back pain *Israel J Med Sci* 2 3 362–370

Hirsch C Jonsson B & Lewin T (1969) Low back symptoms in a Swedish female population *Clin Orthop* 63 171–176

Horal J (1969) The clinical appearance of low back pain disorders in the city of Gothenburg Sweden Comparisons of incapacitated probands with matched controls *Acta Orthop Scand* Suppl 118

Hovind H & Nielsen S (1973) Aendringer i gennemblodningen i subcutis og muskulatur efter kortbølge diathermi. *Dansk Tidskrift for Fysioterapeuter* 4–5 328–332

Hult L (1954) The Munkfors investigation *Acta Orthop Scand* Suppl 16

Hult, L. (1954) Cervical, dorsal and lumbar spinal syndromes *Acta Orthop Scand* Suppl 17

Ikata, T (1965) Statistical and dynamic studies of lesions due to over loading on the spine *Shikoku Acta Med* 40, 262–286

Janda, V (1975) *Muskelfunktionsdiagnostik*. Studentlitteratur, Lund pp 13–23, 266–275 & 278

Jayson, M I V & Barks, J S (1973) Structural changes in the intervertebral disc *Ann Rheum Dis* 32, 10–15

Kaltenborn, F M (1975) *Test segmenti mobilis Columna vertebralis Course 1* pp 44–57 Bygdøy Allé 14, Oslo 2, Norway

Kaltenborn, F M (1975) *Mobilisation 1 Segmenti mobilis columna vertebralis* pp 51–63 Bygdøy Allé 14, Oslo 2, Norway

Kelsey, J L & Hardy, R J (1975) Driving of motor vehicles as a risk factor for acute herniated lumbar intervertebral disc *Amer J Epidem* 102 1, 63–73

Kelsey, J L (1975) An epidemiological study of the relationship between occupations and acute herniated lumbar intervertebral discs *Int J Epid* 4, 197–205

Kelsey, J L (1975) An epidemiological study of acute herniated lumbar intervertebral discs *Rheumatol Rehabil* 14, 144–159

Kendall, P H & Jenkins, J M (1968) Exercises for backache A double blind controlled study *Physiotherapy* 53, 154–157

Lawrence, J S (1955) Rheumatism in coal miners Part III Occupational factors *Brit J Ind Med* 12, 249–261

Leavitt S S, Johnston, T L & Beyer, R O (1971) The process of re covery patterns in industrial back injury Part 2 Predicting outcomes form early case data. *Industr Med Surg* 40, 7–15

Lewin, T (1964) Osteoarthritis in lumbar synovial joints *Acta Orthop Scand* Suppl 73

Lewit, K (1977) *Manuelle Medizin im Rahmen der Medizinischen Rehabilitation* Vol 2, Johann Ambrosius Barth, Leipzig

Lidstrom A & Zachrisson, M (1970) Physical therapy on low back pain and sciatica An attempt of evaluation *Scand J Rehabil Med* 2, 37–42

Lidstrom, A & Zachrisson, M (1973) Ryggbesvar och arbetsoformåga. Ryggskolan Ett forsok till mer rationell fysikalisk terapi *Socialmed T* 7 419–422

Lind, G A.M (1974) *Auto-traction Treatment of Low Back Pain and Sciatica.* Thesis, University of Linkoping
Lokander S (1962) Sick absence in a Swedish company A sociomedical study *Acta Med Scand* Suppl 377
Magora A (1970) Investigation of the relation between low back pain and occupation *Industr Med Surg* 39, 31–37
Magora, A (1970) Investigation of the relationship between low back pain and occupation 1 Age sex community education and other factors. *Industr Med Surg* 39 465–471
Magora A (1970) Investigation of the relation between low back pain and occupation 2. Work history *Industr Med Surg* 39 504–510
Magora A. (1972) Investigation of the relation between low back pain and occupation 3 Physical requirements sitting standing and weight lifting *Industr Med Surg* 41 12 5–9
Magora A. (1973) Investigation of the relation between low back pain and occupation 4 Physical requirements bending rotation reaching and sudden maximal effort. *Scand J Rehabil Med* 5 186–190
Magora A (1973) Investigation of the relation between low back pain and occupation 5 Psychological aspects. *Scand J Rehabil Med* 5 191–196
Magora A (1974) Investigation of the relation between low back pain and occupation 6 Medical history and symptoms. *Scand J Rehabil Med* 6 81–88
Magora A (1975) Investigation of the relation between low back pain and occupation 7 Neurological and orthopaedic condition *Scand J Rehabil Med.* 7 146–151
Maroudas A. Stockwell, R.A., Nachemson A. & Urban J (1975) Factors involved in the nutrition of the human lumbar intervertebral disc Cellularity and diffusion of glucose in vitro *J Anat* 120 1 113–130
McGill C M (1968) Industrial back problems – a control program *J Occup Med* 10 4 174–178
Moll J M H & Wright V (1971) Normal range of spinal mobility *Ann Rheum Dis.* 30 381–386
Nachemson A.L. (1960) Lumbar intradiscal pressure *Acta Orthop Scand.* Suppl 43
Nachemson A.L. & Morris, J M (1964) In vivo measurements of intradiscal measure *J Bone Joint Surg* 46–A 1077–1092.
Nachemson A.L. & Elfström G (1970) Intravital dynamic pressure measurements in lumbar discs. *Scand J Rehabil Med* Suppl 1

Nachemson, A L, Lewin, T, Maroudas, A & Freeman, M A R (1970) In vitro diffusion of dye through the end plates and the *annulus fibrosus* of human lumbar intervertebral discs *Acta Orthop Scand* 41, 589–607

Nachemson, A L (1971) Low back pain Its etiology and treatment *Clin Med* 78, 18–24

Nachemson, A L & Andersson, G B J (1975) *Classification of low back pain* Presented to the International Society for the Study of the Lumbar Spine, London

Nachemson, A L (1976) Lumbar intradiscal pressure *The Lumbar Spine and Back Pain* Ed M Jayson, Pitman Med Publ Co Ltd

Nachemson, A L (1976) The lumbar spine An orthopaedic challenge *Spine* 1 1, 59–71

Nagi, S Z, Riley, L E & Newby, L G (1973) A social epidemiology of back pain in a general population *J Chron Dis* 26, 769–779

Natvig, H (1970) Sociomedical aspects of low back pain causing prolonged sick leave A retrospective study *Acta Soc Med Scand* 2–3, 117–126

Naylor, A (1976) Intervertebral disc prolapse and degeneration The biochemical and biophysical approach *Spine* 1 2, 108–114

Naylor, A & Shentall, R (1976) Biochemical aspects of intervertebral discs in ageing and disease *The Lumbar Spine and Back Pain* Ed M Jayson, Pitman Med Publ Co Ltd

Phillips, E L (1964) Some psychological characteristics associated with orthopaedic complaints *Orthop Surg* 2, 165–176

Ransford, A O, Cairns, D & Mooney, V (1976) The pain drawing as an aid to the psychologic evaluation of patients with low back pain *Spine* 1 2, 127–134

Rolander, S D & Blair, W E (1975) Deformation and fracture of the lumbar vertebral end plate *Orthop Clin North Am* 6, 75–81

Roslund, J (1974) *Indications for lumbar disk surgery* Thesis Karolinska institutet, Stockholm

Rothman, R H (1973) The pathophysiology of disc degeneration *Clin Neurosurg* 20, 174–182

Rowe, M L (1969) Low back pain in industry A position paper *J Occup Med* 11 4, 161–169

Seager F G M (1959) Some observations on the incidence and treatment of back injuries in industry *Ann Occup Hyg* 1, 180–185

Statistics from the National Health Insurance Office (NHIO) Gothenburg, Sweden

Sternbach R A Wolf S R. Murphy R.W & Akeson W H (1973) Aspects of chronic low back pain. *Psychosomatics* 14 52–56

Sternbach R A & Timmermans G (1975) Personality changes associated with reduction of pain *Pain* 1, 177–181

Timmermans G & Sternbach R A (1974) Factors of human chronic pain An analysis of personality and pain reaction variables *Science* 184 806–808

Troup J D G , Roantree W B & Archibald R.M (1970) *Survey of cases of lumbar spinal disability A methodological study* Med Officers Broadsheet National Coal Board

Vernon Roberts B & Pirie C J (1973) Healing trabecular microfractures in the bodies of lumbar vertebrae *Ann Rheum Dis* 32 406–412

Westrin C G (1970) Low back sick listing A nosological and medical insurance investigation *Scand J Soc Med* Suppl 7

Westrin C G Hirsch C & Lindegård B (1972) The personality of the back patient. *Clin Orthop* 87 209–216

White, A A Southwick W O & DePonte R.J (1973) Cervical spine fusions – psychological and social considerations *Arch Surg* 106 150–152

White A W M (1966) Low back pain in men receiving workmen s compensation *Can Med Assoc J* 95 50–56

White A W M (1969) Low back pain in men receiving workmen s compensation A follow up study *Can Med Assoc J* 101 2 61–67

Wilfling F J Klonoff H & Kokan P (1973) Psychological demographic and orthopaedic factors associated with prediction of outcome of spinal fusion *Clin Orthop* 90 153–160

Wiltse L.L & Rocchio P D (1975) Preoperative psychological tests as predictors of success of chemonucleolysis in the treatment of the low back syndrome *J Bone Joint Surg* 57–A 4 478–483

Wood P H N & McLeish C.L (1974) Statistical appendix *Ann Rheum Dis* 33 93–105

Wood P H N (1976) Epidemiology of back pain *The Lumbar Spine and Back Pain.* Ed M Jayson Pitman Med Publ Co Ltd

Nachemson, A L Lewin, T, Maroudas, A & Freeman, M A R (1970) In vitro diffusion of dye through the end plates and the annulus fibrosus of human lumbar intervertebral discs. *Acta Orthop Scand* 41, 589–607

Nachemson, A L (1971) Low back pain Its etiology and treatment *Clin Med* 78, 18–24

Nachemson, A L & Andersson, G B J (1975) *Classification of low back pain* Presented to the International Society for the Study of the Lumbar Spine, London

Nachemson A L (1976) Lumbar intradiscal pressure *The Lumbar Spine and Back Pain* Ed M Jayson, Pitman Med Publ Co Ltd

Nachemson, A L (1976) The lumbar spine An orthopaedic challenge *Spine* 1 1, 59–71

Nagi S Z, Riley L E & Newby, L G (1973) A social epidemiology of back pain in a general population *J Chron Dis* 26, 769–779

Natvig, H (1970) Sociomedical aspects of low back pain causing prolonged sick leave A retrospective study *Acta Soc Med Scand* 2–3, 117–126

Naylor, A (1976) Intervertebral disc prolapse and degeneration The biochemical and biophysical approach *Spine* 1 2, 108–114

Naylor, A & Shentall, R (1976) Biochemical aspects of intervertebral discs in ageing and disease *The Lumbar Spine and Back Pain* Ed M Jayson, Pitman Med Publ Co Ltd

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Rolander, S D & Blair, W E (1975) Deformation and fracture of the lumbar vertebral end plate *Orthop Clin North Am* 6, 75–81

Roslund, J (1974) *Indications for lumbar disk surgery* Thesis Karolinska institutet, Stockholm

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History of back pain and clinical factors

Earlier episodes of back pain

	0	1–3	> 3 episodes
Group A	33	28	9
B	33	30	9
C	30	36	9

Onset of symptoms

	Sudden	Insidious
Group A	26	44
B	37	35
C	34	41

Pain index

	Median values p
Group A	43
B	42
C	42

p = points

APPENDIX

DISTRIBUTION OF CONFOUNDING FACTORS IN THE TREATMENT GROUPS

Group A = Back School
Group B = Physical therapy
Group C = "Placebo"

Demographic factors

Age

	<30	30–50	> 50 years
Group A	23	32	15
B	21	41	10
C	31	34	10

Sex

	male	female
Group A	64	6
B	60	12
C	65	10

Rotated posture

	often	regularly	rarely
Group A	40	15	15
B	49	10	13
C	50	12	13

often = > 10 times/hour
regularly = < 10 times/hour but regularly
rarely = 1 – 2 times/week

Lifting (≥ 5 kg)

	often	regularly	rarely
Group A	18	21	31
B	26	15	31
C	23	25	27

often = > 10 times/hour
regularly = < 10 times/hour but regularly
rarely = 1 – 2 times/week

Lifting (≥ 20 kg)

	often	regularly	rarely
Group A	8	17	45
B	7	12	53
C	10	9	56

often = > 1 hour
regularly = < 1 hour, regularly
rarely = 1 – 2 times/week

Vocational factors

Category of employment

	office staff	manual workers
Group A	23	47
B	18	54
C	16	59

Sitting posture

	> 4 hours/day	2–4 hours/day	< 2 hours/day
Group A	20	9	41
B	21	11	40
C	16	14	45

Standing posture

	> 4 hours/day	2–4 hours/day	< 2 hours/day
Group A	43	10	17
B	45	10	17
C	46	19	10

Stooped posture

	often	regularly	rarely
Group A	41	12	17
B	46	13	13
C	53	10	12

often = > 10 times/hour
regularly = < 10 times but regularly
rarely = 1 – 2 times/week

Variation of work

	variation	some variation	no variation
Group A	14	25	31
B	19	31	22
C	17	23	35

Concentration

	much concentration	little concentration
Group A	32	38
B	35	37
C	29	46

Satisfaction with working tasks

	satisfied	not satisfied
Group A	56	14
B	52	20
C	49	26

Satisfaction with working environment

	satisfied	not satisfied
Group A	36	34
B	39	33
C	41	34

Forceful movements

	often	regularly	rarely
Group A	6	12	52
B	8	15	49
C	11	12	52

often = > 10 times/day
regularly = < 10 times/day but regularly
rarely = 1 – 2 times/week

Fixed posture

	fixed	semi fixed	not fixed
Group A	17	12	41
B	19	25	28
C	17	32	26

Pauses

	often	sometimes	rarely
Group A	16	26	28
B	14	39	19
C	14	32	29

often = every hour
sometimes = several times/day
rarely = occasionally

Wish to change work

	yes	no
Group A	19	51
B	21	51
C	23	52

Contact with social welfare authorities

	number of individuals
Group A	7
B	9
C	9

Psychological factors

Hy scale

	0 p	1–5 p	5–10 p	10–20 p
Group A	16	37	12	5
B	11	44	13	4
C	13	42	15	5

p = points

Hs-scale

	0–5 p	5–10 p	10–20 p	> 20 p
Group A	2	10	52	6
B	0	9	59	4
C	2	11	58	4

p = points

Relations to colleagues

	good	fair
Group A	63	7
B	63	9
C	67	8

Tiredness in the back

	never	occasionally	daily
Group A	28	37	5
B	28	33	11
C	27	37	11

Nervousness after work

	rarely	often
Group A	69	1
B	71	1
C	73	2

Fatigue after work

	not tired	tired	very tired
Group A	9	54	7
B	13	53	6
C	13	53	9

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ABSTRACT

A clinical and radiological follow up examination was made in three formerly well examined and defined unilateral samples of Legg Calve Perthes Disease one group of 100 cases with an average age of 2ɔ years another of 33 cases with an average age of 3ɔ years and *finally* a group of 19 cases with an average age of 65 years

The factors known to influence the shape of the head at the *primary* healing in childhood sex age and stage of the disease at time of diagnosis together with shape of the head at *primary* healing were examined concerning their influence on the *late* occurrence of radiological coxarthrosis pain and mobility

Sex and stage had no significant influence on the late fate of the diseased hip Age at onset and shape at the primary healing showed significant influence on the late result

At the 2ɔ and 3ɔ level less than 6 per cent had coxarthrosis and in that case with a significantly *higher frequency* in irregular healed heads compared to normal and flattened ball shapes

At the 6ɔ level in an untreated group there was a high frequency of irregular heads and above 8ɔ per cent coxarthrosis

Pain partly arose from the primary hea ling partly between 20 to 40 years of age During the decade from 2ɔ to 3ɔ years of age only the irregular shaped heads sho wed an increase in occurrence of coxarthrosis

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Key words

Coxa plana Femur head necrosis Legg Perthes disease Osteochondritis Osteone crosis

CONTENTS

INTRODUCTION

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Many authors have pointed out identical prognostic factors for the shape of the head at the *primary* healing

- Sex Boys have generally been reported to have better results than girls This was recently denied by the investigation of Lauritzen

- Age at onset of the disease The younger the better results

- Stage of the disease at establishment of diagnosis and treatment On early relief from weight bearing i e up to early fragmentation the prospects for a good result were better

- Other factors have been mentioned such as different types of course (Catterall) and the degree of destruction during the course of the disease in childhood *These factors* seem however to depend on the stage of the disease when relief from weight bearing took place

Relatively few reports concern the *late* clinical and radiological results The *most* important materials were presented by the following authors

Sundt (1949) 153 hips reexamined 10 to 52 years after the onset of the disease

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Details of the reports will be mentioned later

The general conclusions of these investigations were that primarily *irregular* shape of the hip resulted in a high frequency of late coxarthrosis whereas *normal ball-shaped* heads never had radiological signs of coxarthrosis nor functional disablement A group between the two mentioned consisting of still ball shaped but clearly *flattened* heads were estimated to manage well too

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It was *the purpose* of the present investigation to study the influence on the *late* fate of the affected hip by

1 such factors that determine the primary shape of the head sex, age at onset of the disease, stage of the destruction at the time of treatment, and

2 the shape of the head at the primary healing

In the following, these factors will be related to late results, especially the occurrence of radiological coxarthrosis, pain restriction of mobility, walking ability, and social consequences

Finally it was attempted to estimate the age at which pain and other disablement commenced

A comparison between methods of treatment was not intended

PATIENTS

Patients were traced from three previous Danish theses on LCPD Flemming Møller (1924) Sven Helbo (1953) and Knud Mose (1964)

Møller This thesis was based upon a thorough examination of 72 children or young adults At that time the LCPD was a newly described condition therefore many of the cases comprised in Møller s work were diagnosed after the age of 10 In this way the material comprised seve ral cases attacked before the year 1910

The case histories were unfortunately not provided with sufficient data as to make it possible to trace the patients

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They were all treated for one year with bed rest

Of this material *33 cases* could be traced for the present study

In addition Helbo made an evaluation of long term results in 52 cases partly based on the patients of Møller partly on for mer cases treated on the Seaside Hospital at the same time as Møller s cases

From this second group *11 cases* with an observation time of more than 40 years met for re evaluation in the present study

Mose presented three groups 219 hips in all One group was treated with strict bed rest (78 hips) another with mobilizing bed rest (70 hips) and the third group with a Thomas Splint type of walking calliper (71 hips) In every case the patient was treated through the whole period with presumed weakness of the epiphysis i e for up to two or three years

The cases were taken from the same period 1953 to 1957 Only the first two groups mentioned were searched for the present study Among these *100 cases* met for re examination

In the 1964 evaluation there was found no statistical difference in the distribution of good fair and poor primary radiologi cal results between these two bed rest treated groups Thus in the present study they could be put together in one group

The age distribution mean age and time interval from the mean age at *primary healing* to the mean age at *follow up examination* was set up in *Fig 1–3*

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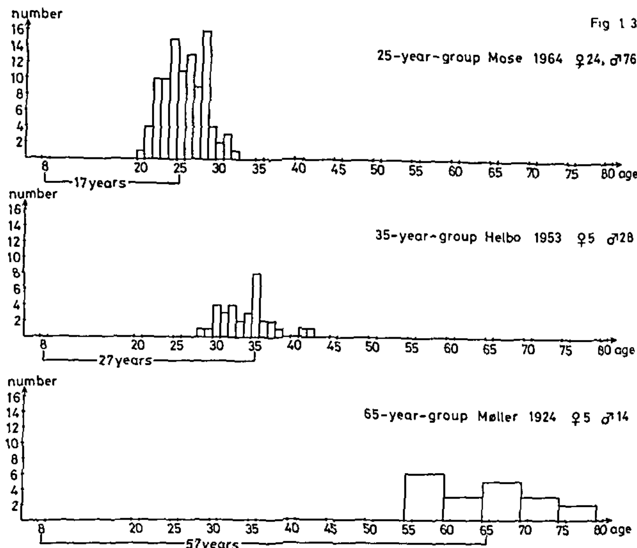
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Statistical notes on the groups

An examination was made concerning the homogeneity between the three test samples with respect to the three factors influencing the primary results sex age at onset of the disease and stage at treatment

– Sex homogeneity certified in the three groups
(χ (2) = 1 3136 p>0 50)

– Age at onset of the disease it was *not* likely to presume homogeneity between the three groups as there was found relatively fewer observations in the young age groups and relatively more in the age group from 5–8 years in the 35 group, than in the other two groups
(χ (4) = 13 0040) 0 01<p<0 025

– Stage at diagnosis and treatment homogeneity certified in the two groups treated
(χ (1) = 0 7634 p>0 50)

The discovery of lack of homogeneity between the groups concerning age may be due to slight differences in the estimation of the time of commencement which was based on judgement partly on the time of the first complaint partly on the stage of the disease at the first x ray picture

PROCEDURE AND METHODS

The follow up examination was carried out during the years 1973 and 1974
Radiological and clinical examinations were made on the same attendance but without the clinician having the opportunity to see the result of the x ray examination before the clinical examination

A Radiology

Examinations were carried out and evaluated by RC and AJ Conventional x ray pictures were taken in frontal view and in frog leg position (lateral view Lauensteins projection)
Furthermore two oblique exposures in erect position were carried out In the first the hip in question was projected anteriorly to the other hip revealing the posterior part of the joint space In the second the examined hip was seen posteriorly to the non examined showing the anterior part of the joint space (Ahlback 1971)
In this way the examination gave detailed information concerning early cartilage destruction
The assessment of the degree of coxarthrosis is given on page 20
Three cases 2 from the 25 group 1 from the 35 group refused x ray examination

B Clinical examination

The clinical examinations were carried out by MU and LH They included a careful case history recorded in a *schedule* comprising information necessary for assessment of pain age at onset of pain daily activities etc
The classifications are shown in table 7 and on page 30
The mobility of the hip joint was examined in the following way – *Flexion* in supine position the non examined leg straight out. *Abduction* in supine position both hips being abducted at the same time *Adduction* in supine position one hip at a time *Rotations* in prone position with knees flexed 90 using the legs as pointers Inward rotation was done with both hips rotated at the same time outward rotation with the legs one at a time
Atrophy was measured in centimeters
The asessment of the degree of restricted mobility is given on page 30

C Radiological measurements

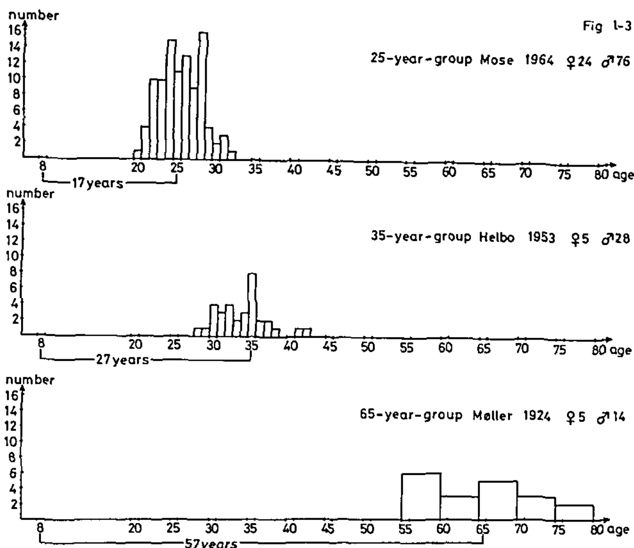
After radiological and clinical examinations measurements of the shape of the heads were undertaken by KM
Measurements were taken from the exposures from the time of primary healing and from the follow up examination
By means of a circle templet the shape of the hips could be divided into *irregular* and ball shaped heads as described among others by Mose (1964) The latter group was divided into two subgroups by means of the templet *flattened ball shape* and *normal ball shape* according to the radius quotient (RQ) described by Meyer (1966)

$$RQ - \frac{\text{radius of diseased head}}{\text{radius of normal head}} \times 100$$

In normal persons the RQ may amount to 115
By this procedure three groups were defined

1 *irregular heads*
2 flattened ball shaped heads — RQ above 115
3 normal ball shaped heads — *RQ below 115*

In Moller s cases the x ray pictures from primary healing could not be traced Therefore the estimation was restricted to ball shaped or irregular heads on the basis of informations given by Moller or by Helbo



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Fig 5 Female LCPD 6 years old Control 56 years old Flattened ball shape RQ 130 No radiological signs of coxarthrosis



Fig 4 Male LCPD 6 years old Control 65 years old ball shape RQ 113 No or slight radiological signs of coxarthrosis



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Fig 6 A and B Male LCPD 10 years old Healed with irregular shape (6 A) Control 28 years old Severe coxarthrosis (6 B)





The RQ is a reliable and easily made estimation of the shape of the head

Among the other methods described to evaluate the degree of flattening, the epiphyseal quotient (EQ) was excluded because the epiphyseal line has disappeared at the time of follow up examination

The joint surface quotient (JSQ) requires the drawing of some construction lines, making it less practical for future clinical use, and endows it with some degree of estimation

A combination of the three quotients, demanding the best result in each of the measurements for the single hip to be put into an ideal group, has been used in some works on the primary results In the present work it was thought to be too strict a measurement to reflect upon the late clinical findings which may be difficult to define with an equal accuracy

Age group at follow up ex	at primary healing			at follow up examination		
	25	35	65	25	35	65
Normel ball shaped	35	16	3	63	17	4
Flattened ball shaped	39	8		12	5	1
Irregular	26	9	13	24	10	14
	100	33	16	99	32	19

Table 1 Number of cases changing from RQ above 115 to RQ below 115 from primary healing to time of follow up

Statistical notes

In order to investigate the evolution of the RQ between the primary and the secondary examination a paired t test (two sided) was performed The original observations were analysed by calculating the difference x = secondary RQ — primary RQ

Only the **25** *and the* **35** *groups could be examined The difference between the RQ evolutions in the two groups was investigated by performing a t test (two sided) on the two independent samples of differences*

25 *group* $n_1 = 75$ $\bar{x} = -8\ 03$ $s = 66\ 831$
An improvement in RQ was likely to occur
$(t\ (74) = -8\ 51\ \ p < 0\ 001)$

35 *group* $n = 22$ $\bar{x} = -3\ 00$ $s = 55\ 619$
A tendency to improvement in RQ was noted
$(t\ (21) = -1\ 84\ \ 0\ 05 < p < 0\ 10)$

Both groups *The same variance of x was noted in the two groups*
$(F\ (74\ 21) = 1\ 1365\ \ p \simeq 0\ 05)$
Improvement in RQ was greater in the **25** *than in the* **35** *group*
$(t\ (95) = -2\ 5730\ \ p \simeq 0\ 01)$

In table 1 the grouping of the *primary* results was compared with the results of the measurements at the secondary examination after the end of growth

Discussion The following was noted

- normal ball shaped heads were still normal and did not change to flattened or irregular shapes
- all primarily irregular heads were still irregular at the fo[illegible] up examination (small differences were due to the few cases who refused x ray examination)
- a significant improvement in RQ was noted among the ball shaped heads especially in the 25 group a fall in number of flattened ball shaped heads and a rise in number of normal sphericity

This must be due to an equal numerical growth in radius in the sound and diseased heads thus leading to a more normal

proportion between their radii during the growth period up to closure of the epiphyseal line

D Preparation for statistics

The data obtained by the procedures mentioned were arranged in groups and put into KH punch cards by KM The comparisons between the frequencies of the different parameters were formulated by a statistician (EH) The χ^2 test was used in most instances The limits of significance for the χ^2 test were stipulated in this manner

$0.05 < p < 0.10$	tendency
$0.01 < p < 0.05$	possible significance
$0.001 < p < 0.01$	significance
$p < 0.001$	high significance

The p values will not be repeated in the single schedules

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RESULTS IN PRESENT STUDY

Radiological coxarthrosis

1 Literature

Sundt (1949) Radiological signs of coxarthrosis was found in 65 hips The primary shape of the heads was divided into four groups spherical, (11 none showed coxarthrosis), oval (56, 16 had radiological coxarthrosis), cylindrical (78, 41 showed coxarthrosis) and angular (8, who had all coxarthrosis)

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Ratliff (1967) gave his results in a summarized pointsystem including both clinical and radiolagical parameters thus preventing comparison to the single parameters used in this work

Eaton (1967) reported the late results of 100 hips as follows 7 excellent 54 good 16 fair and 23 poor (or with arthrodesis)

Gower and Johnston (1971) found moderate and severe degress of coxarthrosis in 9 patients all of whom had healed with flattened heads

Brotherton (1977) used Ratliffs points system According to this 90 per cent obtained good results at the follow up

No one except Laton, dealt with the influence of other primary factors than that of a visual estimation of the primary shape of the head

2 Method of estimation

The radiological examination and the number of projections in the single patient was mentioned in procedure and methods

The estimation of the degree of radiological coxarthrosis was carried through according to a modified Henpret s scheme (Danielsson 1964)

Osteophytes	none	points 0
	at one pole	1
	few	2
	many	3
Joint space	no narrowing	0
	1 2 mm	1
	2 4 mm	2
	above 4 mm	3
Bone structure		
osteoporosis	according to estimate	points 0—3
hyperdensity	no	0
	slight acetabulum	1
	moderate in caput and acetabulum	2
	marked in caput and acetabulum	3
Cysts	none	0
	single caput and acetabulum	1
	more	2
	several	3

The single case may obtain from 0 to 15 points
For practical purposes the cases were finally grouped for statistical arrangement in three categories

Coxarthrosis	none	0	points
	slight	1–4	
	severe	above 5	

3 PRESENT RESULTS

Total occurence of late radiologial coxarthrosis

In Tab 2 the total number of cases with radiological coxarthrosis was drawn up

age group at follow up ex	points for radiol arthr	number	per cent of whole group
25			
(98 cases)	0	73	75 %
	1—4	22	22
	5—8	2	2 /
	9—12	1	1 ∘
	13—15	0	0
35			
(32 cases)	0	°2	69°
	1—4	8	25 /
	5—8	1	3%
	9—12	1	3
	13—15	0	0
65			
(19 cases)	0	1	5 %
	1—4	2	10
	5—8	6	32%
	9—12	3	16%
	13—15	7	37°

Table 2 Number and percentage occurence of radiological coxarthrosis was arranged according to age and degree of radiological coxarthrosis (Three cases refused radiological examination)

Statistics Within the single age group all points from 0—4 and from 5—15 were added The following comparisons were done

25 *versus* 35 *no significant differences*

25 *versus* 65 χ^2 *(1)* = *77 0 high significance*

35 *versus* 65 χ^2 *(1)* = *31 7 high significance*

Discussion It appears that in the two younger groups both relieved consistently during childhood there was the same distribution of none slight and more severe coxarthrosis

For the 65 group of untreated cases the occurrence of radiological coxarthrosis especially in the more severe types was significantly higher

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No one, except Eaton, dealt with the influence of other primary factors than that of a visual estimation of the primary shape of the head

2 Method of estimation

The radiological examination and the number of projections in the single patient was mentioned in procedure and methods

The estimation of the degree of radiological coxarthrosis was carried through according to a modified Henpret s scheme (Danielsson 1964)

Osteophytes	none	*points* 0
	at one pole	1
	few	2
	many	3
Joint space	no narrowing	0
	1 2 mm	1
	2 4 mm	2
	above 4 mm	3
Bone structure		
osteoporosis	according to estimate	points 0—3
hyperdensity	no	0
	slight acetabulum	1
	moderate in caput and acetabulum	2
	marked in caput and acetabulum	3
Cysts	none	0
	single caput and acetabulum	1
	more	2
	several	3

The single case may obtain from 0 to 15 points

For practical purposes the cases were finally grouped for statistical arrangement in three categories

Coxarthrosis	none	0	points
	slight	1–4	
	severe	above 5	

3 Present results

Total occurence of late radiologial coxarthrosis

In Tab 2 the total number of cases with radiological coxarthrosis was drawn up

age group at follow up ex	points for radiol arthr	number	per cent of whole group
25			
(93 cases)	0	73	75 %
	1—4	22	92 /
	5—8	2	2
	9—12	1	1
	13—15	0	0
35			
(32 cases)	0	22	69%
	1—4	8	25%
	5—8	1	3 %
	9—12	1	3%
	13—15	0	0
65			
(19 cases)	0	1	5
	1—4	2	10%
	5—8	6	32 %
	9—12	3	16%
	13—15	7	37%

Table 2 Number and percentage occurence of radiological coxarthrosis was arranged according to age and degree of radiological coxarthrosis (Three cases refused radiological examination)

Statistics Within the single age group all points from 0—4 and from 5—15 were added The following comparisons were done

25 *versus* **35** *no significant differences*

25 *versus* **65** χ^2 *(1) = 77.0 high significance*

35 *versus* **65** χ *(1) = 31 7 high significance*

Discussion It appears that in the two younger groups both relieved consistently during childhood there was the same distribution of none slight and *more* severe coxarthrosis

For the 65 group of untreated cases the occurrence of radiological coxarthrosis especially in the more severe types was significantly higher

Influence of sex on the late occurence of coxarthrosis was shown in *Tab 3*

Radiol arthr in points	Males		Females	
	number	per cent	number	per cent
0	75	65%	21	64%
1—4	25	21%	7	21%
above 5	16	14%	5	15%
	116		33	

Discussion The three age groups were regarded as a whole, considering the small number of female cases The distribution of no, slight and severe coxarthrosis was identical between the two sexes Thus, a difference in *primary* results, females having worse results (Mose), had no bearing on the late occurrence of coxarthrosis

Table 3 Occurence of radiological coxarthrosis arranged according to sex and degree of radiological arthrosis
Three cases refused x ray examination
Statistics χ (2) = 0 059 *No significance*

Influence of age at onset of LCPD on the occurrence of late radiological coxarthrosis

In table 4 only cases from the **25** group and the **35** group were included and the cases regarded together as the two groups were not homogenous concerning age at onset of the disease The mean age for this group as a whole was 27,5 years In the **65** group the age at onset of the disease was not sufficiently defined

Age at onset	≦ 4			5—8			≧ 9		
Degree of radiol coxarthrosis	**25 + 35**		**65**	**25 + 35**		**65**	**25 + 35**		**65**
None	31	86%	0	51	76%	1	13	48%	0
1—4	5	14%	0	15	22%	2	10	37%	0
above 5	0	0	5	1	2%	4	4	15%	7
	36			67			27		

Table 4 Influence of age at onset of LCPD on the late occurence of coxarthrosis The 25 and the 35 groups were united and regarded together (mean age 27 5 years)

Statistics

below 4 versus 5—8 *no statistical difference*
5—8 versus above 9 χ^2 *(1) = 6 9 Significance*
below 4 versus above 9 χ^2 *(1) = 10 5 Significance*

Discussion If all degress of coxarthrosis whether minor or major were united it would show that onset below 4 years involved 14 per cent late coxarthrosis onset between 5 8 involved 24 per cent and onset above 9 as many as 52 per cent The differences in occurrence of coxarthrosis between both of the two young groups compared to the group above 9 years were significant This late finding was in accordance with the finding that age at onset greatly influenced the primary result (Mose Lauritzen)

Influence of stage at onset of treatment on the occurrence of late radiological coxarthrosis

This subject was referred in *table 5*

Stage at treatment	*Early*				*Late*			
Age group	25		35		25		35	
Points for coxarthr	nos		nos		nos		nos	
0	48	73	15	83 %	25	78	7	50
1—4	15	23	3	17	7	22	5	36
> 5	3	4 %	0	0	0	0	2	11
	66		18		32		14	

Table 5 Secondary radiological arthrosis arranged according to stage at relief from weight bearing The 65 group was regarded as untreated and thus excluded from the list

Statistics
Early 25 versus early 35 early 25 versus late 25 and late 25 versus late 35 No significant difference Early 35 versus late 35 χ (1) = 4 07 Possible significance

Discussion No significant conclusions could be drawn from this study Only in the 35 group a possible difference was demonstrated between early and late treatment

The fact that early treatment resulted in better *primary* results (Helbo Mose Lauritzen) found no reflection in the *late* results in the present study

Influence of the primary shape of the head on the late occurrence of coxarthrosis

An all over view of the per centage distribution of none slight and severe radiological coxarthrosis related to primary shape and age groups was shown in the histogram in fig 7

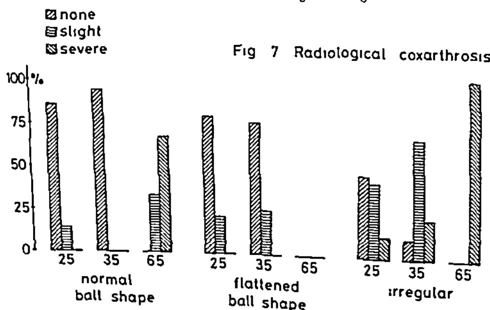


Fig 7 Radiological coxarthrosis

Influence of sex on the late occurence of coxarthrosis was shown in *Tab 3*

Radiol arthr in points	Males		Females	
	number	per cent	number	per cent
0	75	65%	21	64%
1—4	25	21%	7	21%
above 5	16	14%	5	15%
	116		33	

Table 3 Occurence of radiological coxarthrosis arranged according to sex and degree of radiological arthrosis

Three cases refused x ray examination

Statistics χ *(2) = 0 039 No significance*

Discussion The three age groups were regarded as a whole, considering the small number of female cases The distribution of no slight and severe coxarthrosis was identical between the two sexes Thus a difference in *primary* results, females having worse results (Mose), had no bearing on the late occurrence of coxarthrosis

Influence of age at onset of LCPD on the occurrence of late radiological coxarthrosis

In table 4 only cases from the **25** group and the **35** group were included and the cases regarded together as the two groups were not homogenous concerning age at onset of the disease The mean age for this group as a whole was 27 5 years In the **65** group the age at onset of the disease was not sufficiently defined

Age at onset	≦ 4			5—8			≧ 9		
Degree of radiol coxarthrosis	25 + 35		65	25 + 35		65	25 + 35		65
None	31	86%	0	51	76%	1	13	48%	0
1—4	5	14%	0	15	22%	2	10	37%	0
above 5	0	0	5	1	2%	4	4	15%	7
	36			67			27		

Table 4 Influence of age at onset of LCPD on the late occurence of coxarthrosis The 25 and the 35 groups were united and regarded together (mean age 27 5 years)

Statistics

below 4 versus 5—8 *no statistical difference*

5—8 versus above 9 χ *(1) = 6 9 Significance*

below 4 versus above 9 χ^2 *(1) = 10 5 Significance*

Discussion If all degress of coxarthrosis whether minor or major were united it would show that onset below 4 years involved 14 per cent late coxarthrosis onset between 5 8 involved 24 per cent and onset above 9 as many as 52 per cent The differences in occurrence of coxarthrosis between both of the two young groups compared to the group above 9 years were significant This late finding was in accordance with the finding that age at onset greatly influenced the primary result (Mose Lauritzen)

Influence of stage at onset of treatment on the occurrence of late radiological coxarthrosis

This subject was referred in *table 5*

Stage at treatment	*Early*				*Late*			
Age group	25		35		25		35	
Points for coxarthr	nos	%	nos		nos	%	nos	%
0	48	73 %	15	83	25	78	7	50
1—4	15	23 %	3	17	7	22	5	36%
> 5	3	4	0	0	0	0	2	11 %
	66		18		32		14	

Discussion No significant conclusions could be drawn from this study Only in the 35 group a possible difference was demonstrated between early and late treatment

The fact that early treatment resulted in better *primary* results (Helbo Mose Lauritzen) found no reflection in the *late* results in the present study

Table 5 Secondary radiological arthrosis arranged according to stage at relief from weight bearing The 65 group was regarded as untreated and thus excluded from the list

Statistics
Early 25 *versus early* 35 *early* 25 *versus late* 25 *and late* 25 *versus late* 35 *No significant difference Early* 35 *versus late* 35 χ^2 *(1)* = 4 07 *Possible significance*

Influence of the primary shape of the head on the late occurrence of coxarthrosis

An all over view of the per centage distribution of none slight and severe radiological coxarthrosis related to primary shape and age groups was shown in the histogram in fig 7

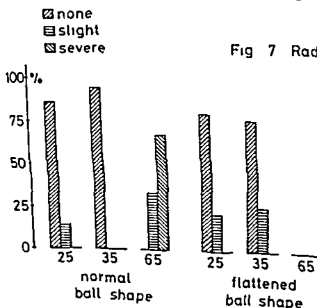


Fig 7 Radiological coxarthrosis

Influence of sex on the late occurence of coxarthrosis was shown in *Tab 3*

Radiol arthr in points	Males		Females	
	number	per cent	number	per cent
0	75	65%	21	64%
1—4	25	21%	7	21%
above 5	16	14%	5	15%
	116		33	

Discussion The three age groups were regarded as a whole, considering the small number of female cases The distribution of no, slight and severe coxarthrosis was identical between the two sexes Thus, a difference in *primary* results, females having worse results (Mose), had no bearing on the late occurrence of coxarthrosis

Table 3 Occurence of radiological coxarthrosis arranged according to sex and degree of radiological arthrosis
Three cases refused x ray examination
Statistics χ *(2) = 0 039 No significance*

Influence of age at onset of LCPD on the occurrence of late radiological coxarthrosis

In table 4 only cases from the **25** group and the **35**-group were included and the cases regarded together as the two groups were not homogenous concerning age at onset of the disease The mean age for this group as a whole was 27 5 years In the **65** group the age at onset of the disease was not sufficiently defined

Age at onset	≦ 4			5—8			≧ 9		
Degree of radiol coxarthrosis	25 + 35		65	25 + 35		65	25 + 35		65
None	31	86%	0	51	76%	1	13	48%	0
1—4	5	14%	0	15	22%	2	10	37%	0
above 5	0	0	5	1	2%	4	4	15%	7
	36			67			27		

Table 4 Influence of age at onset of LCPD on the late occurence of coxarthrosis The 25 and the 35 groups were united and regarded together (mean age 27 5 years)

Statistics
below 4 versus 5—8 no statistical difference
5—8 versus above 9 χ *(1) = 6 9 Significance*
below 4 versus above 9 χ^2 *(1) = 10 5 Significance*

Discussion If all degress of coxarthrosis whether minor or major, were united it would show that onset below 4 years involved 14 per cent late coxarthrosis onset between 5 8 involved 24 per cent and onset above 9 as many as 52 per cent The differences in occurrence of coxarthrosis between both of the two young groups compared to the group above 9 years were significant This late finding was in accordance with the finding that age at onset greatly influenced the primary result (Mose Lauritzen)

Influence of stage at onset of treatment on the occurrence of late radiological coxarthrosis

This subject was referred in *table 5*

Stage at treatment	Early				Late			
Age group	25		35		25		35	
Points for coxarthr	nos	%	nos		nos	%	nos	
0	48	73	15	83	25	78	7	50
1—4	15	23	3	17 %	7	22%	5	36 %
> 5	3	4 %	0	0	0	0	2	11
	66		18		32		14	

Discussion No significant conclusions could be drawn from this study Only in the **35** group a possible difference was demonstrated between early and late treatment

The fact that early treatment resulted in better *primary* results (Helbo Mose Lauritzen) found no reflection in the *late* results in the present study

Table 5 Secondary radiological arthrosis arranged according to stage at relief from weight bearing The 65 group was regarded as untreated and thus excluded from the list

Statistics
*Early **25** versus early **35** early **25** versus late **25** and late **25** versus late **35** No significant difference Early **35** versus late **35** χ (1) = 4 07 Possible significance*

Influence of the primary shape of the head on the late occurrence of coxarthrosis

An all over view of the per centage distribution of none slight and severe radiological coxarthrosis related to primary shape and age groups was shown in the histogram in fig 7

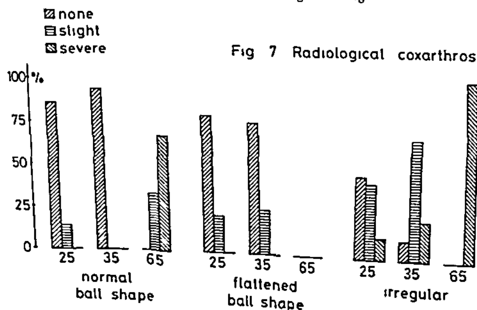


Fig 7 Radiological coxarthrosis

The single numbers and percentages from the histogram were given in table 6 A-C

25 group

Points for coxarthr	normal ballshape		flattened ballshape		irregular	
0	30	86%	31	84%	12	46%
1—4	5	14%	6	16%	11	42%
> 5	0	0	0	0	3	12%
	35		37		26	

Table 6 A
Statistics Normal versus flattened No significance Flattened versus irregular χ^2 (1) = 9.97 Significance Normal versus irregular χ^2 (1) = 10.88 High significance

35 group

	normal ballshape		flattened ballshape		irregular	
0	15	100%	6	75%	1	11%
1—4	0	0	2	25%	6	67%
> 5	0	0	0	0	2	22%
	15		8		9	

Table 6 B
Statistics Normal versus flattened No significance Flattened versus irregular χ^2 (1) = 7.13 Significance Normal versus irregular χ^2 (1) = 20.00 High significance

65 group

	normal ballshape		flattened ballshape	irregular	
0	0	0		0	
1—4	1	33%		0	
> 5	2	67%		13	100%
	3			13	

Table 6 C
Statistics Ballshape versus irregular χ^2 (1) = 4.62 Possible significance

Discussion In the present study no difference in occurrence of late coxarthrosis was found between normal and flattened ball shapes

Both in the **25**- and in the **35**-group, a significantly higher occurrence of coxarthrosis was found among irregular shapes as compared to normal and flattened heads

Furthermore a study was made to see what happened to normal, flattened and irregular hips from a mean age of 25 to that of 35 (comparison vertically between tabel 6 A and 6 B)

*Normal **25** versus **35** no significant increase*

Flattened **25** versus **35** no significant increase

Irregular **25** versus **35** χ^2 (1) 3.5 By one tail test this was possibly significant ($0.01 < p < 0.05$)

By two tail test a tendency to increase was shown ($0.10 < p < 0.05$)

Discussion No increase could be shown in occurrence of coxarthrosis from the age of 25 to 35 assuming normal or flattened ball shape For the irregular heads a possible increase in coxarthrosis was demonstrated from 25 to 35 years in mean age

Occurrence of pain

1 LITERATURE

Pain was recorded in earlier investigations as follows

Sundt (1949) reported 17 cases with reduced working capacity and among them 9 with severe complaints out of the material of 135 cases

Helbo (1953) out of his 52 late cases reported that only 8 were symptomfree while the rest had some disability

Evans (1958) found only trivial subjective complaints among 52 cases

Danielsson (1964) among 35 patients found 7 with pain all of whom belonged to the most deformed cases

Ratliff (1967) noted that four fifths of his 34 hips were free from pain while only two fifths had good hips radiologically

Eaton (1967) out of his 85 non operated cases found 4з without pain and 22 with slight 1з with moderate and 3 with severe pain

Cower and Johnston (1971) found absent or mild pain among their 36 cases only 3 cases having required operation

Steinhauser (1971) 11 per cent who complained of pain were all in poor quotient groups

2 Assessment of pain

The grading of pain was carried through according to a modified Merle d Aubigny statement

1 No pain

⁴ Pain when starting Capable of moderate work and sport

Requir ng treatment

3 Starting pain and pain again after 1 00 metres walk ng Rarely analgesics Demand ng periodic t eatment (heat etc)

4 Starting pain and pain after 400—1 00 metres walk ng *Frequently analgesic and antirheuma ti dr gs* Demands often physical medicine treatment

5 Resting pain a d pain before 400 metres walk ing Analgesics daily

6 Strong pers tent pain prevent ng sleep

Table ι Assessment of pain

In the present study with its comparatively small number of cases with secondary disablement distinguishments were only made between three groups

1 No pain

2 Slight pain (group 2)

3 Severe pain corresponding to pain requiring treatment

3 Present results

Localisation of pain

Pain was complained of in 60 cases, solely in the adductor region in 26 cases in the trochanteric region in 19 cases and in both regions in 1з cases among whom 3 also complained of low back pain The localisations were analysed and showed no specific and statistically significant relation to other parameters *especially not to radiological coxarthrosis*

Total occurrence of pain

An all over view of the 60 cases having pain was arranged in *table 8*

Age group	25 group		35 group		65 group	
p	l ght	ev e	sl ght		l ght	ev
nos	22	10	11	4	2	11
	⁰	10 ₀	33 ₀	12	10	ɔ8 ₀

Table 8 60 cases complaining of pain recorded according to age group and degree of pain

Statistics

25 group *versus* 35 group *No significant diff*

35 group *versus* 65 group χ (1) = 9 40 Signific

25 group *versus* 65 group χ (1) = 10.ɔ Signific

Discussion Between the 25 and the 35 groups no increase in pain nor difference in severity of pain could be demonstrated The 65 group had a significantly higher occurrence of pain especially in the group of severe pain

Influence of sex on the late occurrence of pain was shown in table 9

Sex	male		female	
number	118		34	
no pain	76	64%	16	47%
slight pain	28	24%	7	21%
severe pain	14	12%	11	32%

Table 9 Occurence of pain related to sex
Statistics χ^2 (1) = 8 16 Possible significance

Discussion The females comprised 22 per cent of the whole material, which was in accordance with other materials published The three groups were looked upon as a whole because of the small number of females compared to males A possible significant preponderance of more severe complaints of pain was noticed

Influence of age at onset of LCPD on the late occurrence of pain

In the **25**, **35**- and **65**-groups there was found absence of homogeneity concerning age distribution at the onset of LCPD

Comparison (table 10) was therefore made only between the united **25** *and* **35** groups The **65** group which was in itself small and difficult to compare to the others, was merely added in brackets

Age group at onset	≦ 4			5—8			≧ 9			
group at follow up ex	**25+35**		(65)	**25+35**		(65)	**25+35**		(65)	
no pain	31	82%	(1)	43	64%	(4)	12	43%	(7)	
slight	4	11%	(1)	19	28%	(1)	10	36%	(0)	
severe	3	7%	(3)	5	8%	(2)	6	21%	(6)	86%
	38		(5)	67		(7)	28		(7)	

Table 10 Distribution of patients complaining of pain related to age at onset of LCPD
Statistics »No pain compared to »slight and severe pain combined
< 4 versus 5—8 χ (1) = 3 5 not significant
5—8 versus > 9 χ (1) = 3 6 not significant
< 4 versus > 9 χ (1) = 10 6 significant

Discussion There was found to be decrease in percentage occurrence of painless hips with increasing age at onset of the disease (82–64–43 per cent) At the same time slight and severe pain increased in percentage occurrence (18–36–57 per cent) These findings were however only significant when comparing the group below 4 to that above 9 at onset of LCPD The **65** group showed as expected a high frequency of pain in the group attacked late (86 per cent) The numbers were too small for statistical comparisons

Influence of stage at relief from weight bearing on the late occurrence of pain

It was attempted to elucidate this subject in *table 11*

Age group	Early 25		Early 35		Late 25		Late 35	
no pain	46	0 %	11	58	22	65 %	7	50
slight	13	20%	5	19 %	9	26%	6	43
severe	7	10 %	3	16	3	9	1	7 %
	66		19		34		14	

Table 11 Influence of stage at onset of treatment on the late occurrence of pain The 65 group was regarded as untreated

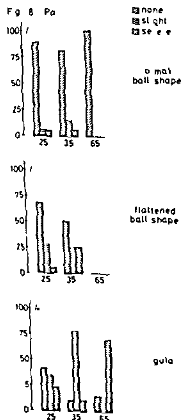
Discussion The influence of early or late commencement of treatment on the late occurrence of pain seemed insignificant This was in accordance with the findings of Eaton (1967)

A clear influence of stage on the *primary* result did not bring its influence to bear on the late result in this study

Statistics All comparisons between the columns showed no significance

Influence of the primary shape of the head on the late occurrence of pain

In the histogram fig 8 the percentage oc currence of cases complaining of pain was arranged according to primary shape and age groups



Details were given in *table 12*

25 group

	normal ballshape		flattened ballshape		irregular	
no pain	31	89%	26	67 %	11	42%
slight	2	5 %	11	28%	9	35%
severe	2	5 %	2	5%	6	23 %
	35		39		26	

Table 12 A Slight and severe combined
Statistics Normal versus flattened ball shape no significance Flattened ball shape versus irregular no significance Normal ball shape versus irregular χ^2 (1) = 14 8 high significance

35 group

no pain	13	81 5	4	50%	1	11%
slight	2	12 5	2	25	7	78 %
severe	1	6 %	2	25%	1	11
	16		8		9	

Table 12 B
Statistics Slight and severe combined Normal ball shape versus flattened no significance Flattened ball shape versus irregular no significance Normal ball shape versus irregular χ^2 (1) = 11.5 / gl significance The numbers were very small

65 group

no pain	3	100			2	15 %
slight	0				2	15 %
severe	0				9	0 %
	3				13	

Table 12 C
Statistics Numbers very small Slight and severe combined Ball shape versus irregular χ^2 (1) = 8 1% significant

Discussion A clear change in occurrence of pain from normal to irregular heads was established

For the **25** group (tab 12 A) there was a gradual fall in 'no pain' from group to group (89–67–42 per cent) and a corresponding rise in occurrence of 'slight and severe pain' (10–33–58 per cent) But only comparisons between normal and irregular shapes were statistically significant

For the **35** group the same tendencies were demonstrated (tab 12 B)

In the **65** group a total of 85 per cent of the irregular shapes were estimated to have slight and severe pain The nine cases complaining of severe pain all appeared in the groups above 4 points (see tab 7)

A study was made concerning a possible change from the age of 25 to that of 35 (columns in tab 12 A and 12 B read vertically)

Neither normal nor flattened ball shaped heads showed any significant increase in occurrence of pain during the decade mentioned

In the group of irregular heads there was a tendency towards an increase in occurrence of pain from the mean age of 25 to that of 35

(χ^2 (1) = 2.89 $0.05 < p < 0.10$)

Secondary pain was finally correlated to *secondary radiological* coxarthrosis in tab 13

Discussion Convincing correlation was found between radiological coxarthrosis and complaints of pain at the follow up examination

Table 13 Correlation between degree of radiological coxarthrosis and pain at the time of follow up 119 out of 152 cases accepted radiological examination

Radiological coxarthrosis	no (96)		slight (32)		severe (21)	
No or slight pain (125)	90	95%	27	84%	8	38%
severe pain (24)	6	5%	5	16%	13	62%
	96		32		21	

Statistics
No radiol coxarthrosis versus slight No signif
Slight versus severe χ^2 (1) = 12.10 high signif
No versus severe χ^2 (1) = 39.23 high signif

Age at onset of pain

1 *Literature*

Sundt (1949) reported only 22 per cent symptomfree at the primary healing

Max Ruelle (1961) made a survey of one thousand cases of coxarthrosis with the aim to find the proportion between primary and secondary ostearthrosis and define the time in life when pain arose All patients were referred to a rheumatological clinic and the indication for the starting points of complaints was simply the need for treatment

271 cases had ostearthrosis secondary to diseases or traumas during childhood and youth Among these 113 might be like LCPD cases according to the description of Ruelle

The mean age for beginning *secondary* coxarthrosis was found to be 10–44 years the majority of cases occurring between 30 to 50 years of age (76 cases out of 113)

The mean age for beginning *primary* coxarthrosis was 57 years with a span from 50 to 70 years

Ratliff (1967) found signs of deterioration in pain and movement in 6 patients out of 34 during a period of observation of 12 years from his first to his second examination In the latter the maximum age was 40 years

Present study

60 patients complaining of pain were arranged according to their own statement on the age at onset of pain (table 14)

Age	below 10		10—20		20—40		above 50 years	
degree	slight	severe	slight	severe	slight	severe	slight	severe
	11	*9*	7	*1*	17	*11*	0	*4*

Table 14 Age at onset of pain according to the patients own recollection

Discussion The age at onset of complaints was difficult to establish with accuracy in a questionnaire

The pain in the present cases was not as severe as in Ruelles cases in need of treatment This may explain the fall in age group to about 10 years younger in the present material as compared to Ruelles

Cases with severe pain occurred partly from the primary healing in childhood like the findings of Sundt partly from the decades from 20 to 40 years of age

In the years from 10 to 20 pain seldom arose

Both below 10 and from 20 to 40 years of age severe degrees of pain occurred mainly among irregularly shaped heads

Further reference was made to table 12 A statistical tendency to a reversal in occurrence of pain from the 25 to the 35 group was shown in the irregular heads only

The same tendency was shown concerning occurrence of radiological coxarthrosis (table 6 A and B) and of mobility (table 20 A and B)

Thus the present study seemed to support the indications of Ruelle concerning age at onset of pain caused by LCPD in childhood Also Meyer (1977) was of the same opinion Possibly a somewhat earlier beginning for the complaints was demonstrated in the present work This early onset of complaints was however limited to irregular heads

Restriction of mobility

1 Literature

Different authors have estimated movement of the hip by a variety of methods that prevent comparison

Sundt (1949) grouped all degrees of restriction from the slightest to the completely ankylosed hips in one group and completely free movements in the other

51 cases showed restriction of flexion 109 of abduction 45 of adduction 59 of supi

Discussion A clear change in occurrence of pain from normal to irregular heads was established

For the **25**-group (tab 12 A) there was a gradual *fall* in no pain from group to group (89–67–42 per cent) and a corresponding rise in occurrence of slight and severe pain' (10–33–58 per cent) But only comparisons between normal and irregular shapes were statistically significant

For the **35** group the same tendencies were demonstrated (tab 12 B)

In the **65**-group a total of 85 per cent of the irregular shapes were estimated to have slight and severe pain The nine cases complaining of severe pain all appeared in the groups above 4 points (see tab 7)

A study was made *concerning* a possible change from the age of 25 to that of 35 (columns in tab 12 A and 12 B read vertically)

Neither normal nor flattened ball shaped heads showed any significant increase in occurrence of pain during the decade mentioned

In the group of irregular heads there was a tendency towards an increase in occurrence of pain from the mean age of 25 to that of 35

(χ (1) = 2 89 0 05 < p < 0 10)

Secondary pain was finally correlated to *secondary radiological* coxarthrosis in tab 13

Discussion Convincing correlation was found between radiological coxarthrosis and complaints of pain at the follow up examination

Radiological coxarthrosis	no (96)		slight (32)		severe (21)	
No or slight pain (125)	90	95%	27	84%	8	38%
severe pain (24)	6	%	5	16%	13	62%
	96		32		21	

Table 13 Correlation between degree of radiological coxarthrosis and pain at the time of follow up 149 out of 159 cases accepted radiological examination

Statistics
No radiol coxarthrosis versus slight No signif
Slight versus severe χ (1) = 12 10 high signif
No versus severe χ (1) = 39 93 high signif

Age at onset of pain

1 *Literature*

Sundt (1949) reported only 22 per cent symptomfree at the primary healing

Max Ruelle (1961) made a survey of one thousand cases of coxarthrosis with the aim to find the proportion between primary and secondary ostearthrosis and define the time in life when pain arose

All patients were referred to a rheumatological clinic and the indication for the starting points of complaints was simply the need for treatment

271 cases had ostearthrosis secondary to diseases or traumas during childhood and youth Among these 113 might be like LCPD cases according to the description of Ruelle

The mean age for beginning *secondary* coxarthrosis was found to be 40–44 years the majority of cases occurring between 30 to 50 years of age (76 cases out of 113)

The mean age for beginning *primary* coxarthrosis was 57 years with a span from 50 to 70 years

Ratliff (1967) found signs of deterioration in pain and movement in 6 patients out of 34 during a period of observation of 12 years from his first to his second examination In the latter the maximum age was 40 years

Present study

60 patients complaining of pain were arranged according to their own statement on the age at onset of pain (table 14)

Age	below 10		10—20		20—40		above 50 years	
degree	slight 11	severe 9	slight 7	severe 1	slight 17	severe 11	slight 0	severe 4

Table 14 Age at onset of pain according to the pat ients own recollection

Discussion The age at onset of complaints was difficult to establish with accuracy in a questionnaire

The pain in the present cases was not as severe as in Ruelles cases in need of treatment This may explain the fall in age group to about 10 years younger in the present material as compared to Ruelles

Cases with severe pain occurred partly from the primary healing in childhood like the findings of Sundt partly from the decades from 20 to 40 years of age

In the years from 10 to 20 pain seldom arose

Both below 10 and from 20 to 40 years of age severe degrees of pain occurred mainly among irregularly shaped heads

Further reference was made to table 12 A statistical tendency to a reversal in occurrence of pain from the **25** to the **35** group was shown in the irregular heads only

The same tendency was shown concerning occurrence of radiological coxarthrosis (table 6 A and B) and of mobility (table 20 A and B)

Thus the present study seemed to support the indications of Ruelle concerning age at onset of pain caused by LCPD in childhood Also Meyer (1977) was of the same opinion Possibly a somewhat earlier beginning for the complaints was demonstrated in the present work This early onset of complaints was however limited to irregular heads

Restriction of mobility

1 Literature

Different authors have estimated movement of the hip by a variety of methods that prevent comparison

Sundt (1949) grouped all degrees of restriction from the slightest to the completely ankylosed hips in one group and completely free movements in the other

51 cases showed restriction of flexion 109 of abduction 45 of adduction 59 of supi

Discussion A clear change in occurrence of pain from normal to irregular heads was established

For the **25** group (tab 12 A) there was a gradual fall in no pain from group to group (89–67–42 per cent) and a corresponding rise in occurrence of 'slight and severe pain' (10–33–58 per cent) But only comparisons between normal and irregular shapes were statistically significant

For the **35** group the same tendencies were demonstrated (tab 12 B)

In the **65**-group a total of 85 per cent of the irregular shapes were estimated to have slight and severe pain The nine cases complaining of severe pain all appeared in the groups above 4 points (see tab 7)

A study was made concerning a possible change from the age of 25 to that of 35 (columns in tab 12 A and 12 B read vertically)

Neither normal nor flattened ball shaped heads showed any *significant* increase in occurrence of pain during the decade mentioned

In the group of irregular heads there was a tendency towards an increase in occurrence of pain from the mean age of 25 to that of 35

(χ (1) = 2 89 0 05 < p < 0 10)

Secondary pain was finally correlated to *secondary radiological* coxarthrosis in tab 13

Discussion Convincing correlation was found between radiological coxarthrosis and complaints of pain at the follow up examination

Radiological coxarthrosis	no (96)		slight (32)		severe (21)	
No or slight pain (125)	90	95%	27	84%	8	38%
severe pain (24)	6	5%	5	16%	13	62%
	96		32		21	

Table 13 Correlation between degree of radiological coxarthrosis and pain at the time of follow up 149 out of 157 cases accepted radiological examination

Statistics
No radiol coxarthrosis versus slight No signif
Slight versus severe χ *(1) = 12 10 high signif*
No versus severe χ^2 *(1) = 39 23 high signif*

Age at onset of pain

1 Literature

Sundt (1949) reported only 22 per cent symptomfree at the primary healing

Max Ruelle (1961) made a survey of one thousand cases of coxarthrosis with the aim to find the proportion between primary and secondary ostearthrosis and define the time in life when pain arose All patients were referred to a rheumatological clinic and the indication for the starting points of complaints was simply the need for treatment

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Present study

60 patients complaining of pain were arranged according to their own statement on the age at onset of pain (table 14)

Age	below 10		10—20		20—40		above 50 years	
degree	slight	severe	slight	severe	slight	severe	slight	severe
	11	9	7	1	17	11	0	4

Table 14 Age at onset of pain according to the pat ients own recollection

Discussion The age at onset of complaints was difficult to establish with accuracy in a questionnaire

The pain in the present cases was not as severe as in Ruelles cases in need of treatment This may expl in the fall in age group to about 10 years younger in the present material as compared to Ruelles

Cases with severe pain occurred partly from the primary healing in childhood like the findings of Sundt partly from the decades from 20 to 40 years of age

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Both below 10 and from 20 to 40 years of age severe degrees of pain occurred mainly among irregularly shaped heads

Further reference was made to table 12 A statistical tendency to a reversal in occur*rence of pain from the* **25** *to the* **35** *group* was shown in the irregular heads only

The same tendency was shown concerning *occurrence of radiological coxarthrosis* (table 6 A and B) and of mobility (table 20 A and B)

Thus *the present study seemed to support the indications of Ruelle concerning age* at onset of pain caused by LCPD in child hood Also Meyer (1977) was of the same opinion Possibly a somewhat earlier be ginning for the complaints was demon strated in the present work This early onset of complaints was *however limited* to irregular heads

Restriction of mobility

1 Literature

Different authors have estimated move ment of the hip by a variety of methods that prevent comparison

Sundt (1949) grouped all degrees of restriction from the slightest to the com pletely ankylosed hips in one group and completely free movements in the other

51 cases showed restriction of flexion 109 of abduction 45 of adduction 59 of supi

nation, 75 of pronation and 65 of hyperextension

A percentage specification of restriction of movement could not be tabulated, as a summing up of the above mentioned figures did not balance with the total

Evans (1958) regarded a direction of movement as being limited when it showed a restriction of 10 degrees or less as compared to the normal hip

14 cases showed limitation in one direction, 3 in two directions, and 10 in three or more directions 25 hips were completely free The movements restricted were abduction (17 cases) lateral rotation (17 hips), extension (11 hips) and medial rotation (10 hips)

Danielsson (1964) according to an index system found excellent and good mobility in all cases whereas none were fair or poor

Ratliff (1967) found movement full or with terminal limitation in 20 of his 34 cases

Eaton (1967) In 97 hips not operated upon 54 were found to have free movement 23 hips showed 75 per cent reduction in mobility 13 hips had 50–75 per cent reduction and 7 hips had below 50 per cent mobility left

Steinhauser (1971) among 75 cases referred 7 per cent with limited mobility and 93 per cent completely free

Gower and Johnston (1971) in their case report referred 4 cases with a total mobility above 260 degrees 9 cases from 211–260 degrees and 23 below 210 degrees

2 Method of estimation

According to the degrees of movement noted at the clinical examination described in page 13 the patients were grouped in the following two ways

1 Sum of movements above 260 degrees

–	211 – 260	–
–	161 – 210	–
–	101 – 160	–
–	61 – 100	–
–	0 – 60	–

(This classification was indicated by Harry K Sorensen)

2 Limitation of movement in the diseased hip amounted to 50 per cent of the movement in the normal hip in

no direction, 1 2 3 4 5 or 6 directions

This quite rough 50 per cent-estimate was given in order to avoid such errors as limitation caused by pain by mental aggravation or by different estimates by the single examiner etc

The two methods were correlated in table 15 It is evident that there was accordance between the two criterias of classification (χ^2 (2) = 32 65 $p < 0.005$)

For practical purposes only three mobility groups were used in the following

Free	sum above 260 degrees
Slight restriction	sum 211 – 260 degrees
Severe –	sum below 210 degrees

No attempt was made to assess the value of the restriction of a single movement by an index system (Danielsson 1964)

Number of directions restricted more than 50 of the normal	none	1 direction	2 or more
sum of movements			
above 260 (103)	90	15	0
211—260 (20)	2	14	4
below 210 (27)	0	3	24
	92	32	28

Table 15 Comparison between two methods of estimation of restriction of movement
Statistics χ (2) = 32 6 significance

3 Present results

A complete review of the occurrence of limitation of movement was arranged in *tab 16*

Age group	25		35		65	
movement						
above 260	79	93 %	22	79%	4	31 %
11— 60	14		4		2	
below 210	7	7 %	7	21 %	13	69%
	100		33		19	

Table 16 152 cases arranged according to range of movement in degress and age group at follow up examination

Statistics free and slight combined
25 *versus* 35 *group* χ (1) = 5 3 *possible signif*
35 *versus* 65 *group* χ (1) = 9 11 *significant*
25 *versus* 65 *group* χ² (1) = 37 9 *high signif*
Excess of severe restriction in the 65 *group*

Discussion Restriction of movement to below a sum of 210 degrees occurred with increasing frequency with increasing age

The occurrence of the *single directions* recorded as reduced to less than 50 per cent of the normal side was shown in tab 17

Age group	25	35	65	sum
flexion	2	0	5	7
abduction	4	2	11	17
adduction	3	3	8	14
outward rot	17	10	11	38
inward rot	22	7	14	43
hyperextension	0	0	1	1
				160

Table 17 Directions of movement restricted more than 50° recorded in age groups

From tab 17 it appeared that rotations were far the most frequent movements to be limited

The following observations may be added

- In cases of *no pain* 20 directions were limited all of which were rotations
- In cases with *slight pain* 37 directions were limited Of these 29 were rota tions (78 per cent)
- In the case of *severe pain* 63 directions were reduced
  Among these 32 (51 per cent) were rota tions 14 (22 per cent) abduction 11 (17 per cent) adduction 5 (8 per cent) flexion and 1 (2 per cent) hyperexten- sion

Influence of sex on late occurrence of limitation of mobility was shown in *table 18*

	male		female	
above 260	83	70	22	65 %
211—260	14	12	6	17 5
below 210	21	18%	6	17.5%
	118		34	

Table 18 152 cases arranged according to range of movement and sex
Statistics Three age groups combined because of the small number of females Homogeneity in di stribution between the two columns

Discussion The influence of sex on the *primary* result could not be confirmed concerning the *secondary* result in this study

Influence of age at onset of LCPD on the late occurrence of limitation of movement, was shown in *table 19*

Age at onset age group	≦ 4 25+35		65	5—8 25+35		65	≧ 9 25+35		65
above 260	33	87%	1	52	78%	3	16	57%	0
211—260	4	11%	0	10	15%	1	4	14%	1
below 210	1	2%	4	5	7%	3	8	29%	6
	38		4	67		7	28		7

Table 19 Restriction of movement arranged according to age at onset of LCPD and age group at follow up examination

Statistics The 25 *and* 35 *groups combined The* 65 *group was inserted for comparison Slight and severe added*

< 4 versus 5—8 No significance

5—8 versus > 9 $\chi^2 (1) = 4.06$ *possible significance*

< 4 versus > 9 $\chi^2 (1) = 7.43$ *significance*

Discussion There was found an apparent rise in occurrence of reduced mobility with increasing age (13 – 22 – 43 per cent) This was significant when comparing the youngest with the oldest and the middle with the oldest group An influence of age at onset of disease on the *primary* result was stated for the *late* result too

Influence of the primary shape of the head on the late occurrence of limitation of movement

From the histogram in *fig 9* there appeared to be a clear tendency towards good mobility in groups with primary normal and flattened ball shaped heads Among primarily irregular heads the frequency of reduced mobility increased

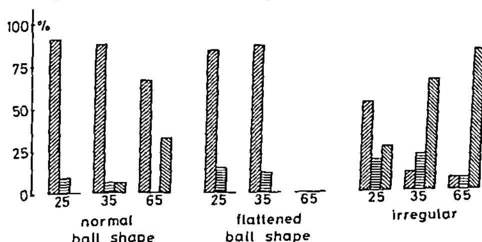


Fig 9 Restriction of movement

The figures from the histogram were tabulated in *table 20*

25 group	normal ball shape		flattened ball shape		irregular	
range of motion						
above 260	32	91 %	33	85°	14	54°
211—260	3	9%	6	15°	5	19 °
below 210	0	0	0	0	7	27°
	35		39		26	

Table 20 A Mobility related to primary shape
Statistics Normal versus flattened ball shape No significance Flattened versus irregular χ^2 (1) = 7.37 significance Normal ball shape versus irregular χ^2 (1) = 11.36 high significance

35 group						
above 260	14	88°	7	88	1	11
211—260	1	6%	1	12°°	2	22
below 210	1	6 %	0		6	67 %
	16		8		9	

Table 20 B Mobility related to primary shape
Statistics Numbers of patients very small Normal versus flattened ball shape No significance Flattened versus irregular χ^2 (1) = 9 91 significance Normal ball shape versus irregular χ^2 (1) = 14.00 high significance

65 group				
above 260	2	67	1	7 5
211—260	0		1	7,5
below 210	1	33	11	850
	3		13	

Table 20 C Mobility related to primary shape
Statistics Very small numbers of patients Ball shape versus irregular χ^2 (1) = [illegible]56 possible significance

Further statistical calculations were made *in the vertical* columns in table 20 A to 20 B concerning changes in mobility between the age of 25 to that of 35

Normal shapes no significance

Flattened shapes no significance

Irregular 25 group versus irregular 35 group χ (1) = 4 98 possible significance

Discussion No difference could be demonstrated in mobility between normal and flattened ball shaped heads In the 25 group as well as in the 35 group irregular heads showed a significantly higher frequency of limitation of movement compared to normal and flattened ball shaped heads

Among normal and flattened ball shapes no changes were traced from the age of 25 to that of 35 On the contrary the irregular heads showed a possible significant increase in limitation of mobility during that decade

Secondary mobility compared to secondary radiological *coxarthrosis* (table 21) and to *pain* (table 22)

Mobility	> 260		211—260		< 210	
no radiological arthrosis	82	80 °	12	69 °	1	4°°
slight	19	18°	5	26 °	8	30
severe	2	2°°	1	5 °	18	66
total 149	103		19		27	

Table 21 Secondary mobility related to radiological arthrosis Three cases refused x ray examination
Statistics Criterias of classification χ^2 (4) = 85 46 $p < 0.001$ No independance between the two criterias of classification

Influence of age at onset of LCPD on the late occurrence of limitation of movement, was shown in *table 19*

Age at onset age group	≦ 4 25+35		65	5—8 25+35		65	≧ 9 25+35		65
above 260	33	87%	1	52	78%	3	16	57%	0
211—260	4	11%	0	10	15%	1	4	14%	1
below 210	1	2%	4	5	7%	3	8	29%	6
	38		4	67		7	28		7

Table 19 Restriction of movement arranged according to age at onset of LCPD and age group at follow up examination

Statistics The 25 *and* 35 *groups combined The* 65 *group was inserted for comparison Slight and severe added*

< 4 versus 5—8 No significance

5—8 versus > 9 χ^2 *(1) = 4 06 possible significance*

< 4 versus > 9 χ^2 *(1) = 7 43 significance*

Discussion There was found an apparent rise in occurrence of reduced mobility with increasing age (13 – 22 – 43 per cent) This was significant when comparing the youngest with the oldest, and the middle with the oldest group An influence of age at onset of disease on the *primary* result was stated for the *late* result too

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From the histogram in *fig 9* there appeared to be a clear tendency towards good mobility in groups with primary normal and flattened ball shaped heads Among primarily irregular heads the frequency of reduced mobility increased

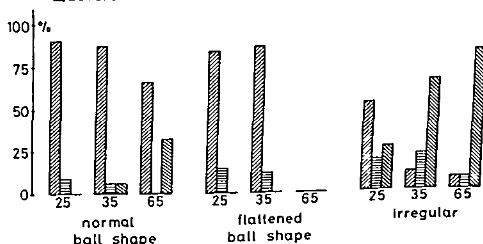


Fig 9 Restriction of movement

PRESENT STUDY

An attempt was made to code the present cases into a scheme for functional capacity like that of Daniels on However nearly all cases fell into the best groups with an absence of overflow to other groups which made statistical comparisons impossible

For that reason it was attempted to extract the walking ability alone It was arranged in *three groups* according to a procedure of estimation resembling that for pain and mobility

Discussion The results of this study were so close to the findings concerning radiological coxarthrosis pain and mobility that it was found needless to repeat the same conclusions regarding on the one hand walking disability and on the other 1) lack of treatment (65 group) 2) high age group at commencement of treatment 3) primary shape of the head and 4) severe secondary radiological coxarthrosis

Social conditions

A brief history of social and allied conditions was taken in all cases They could be outlined in a scheme as follows

	25		35		65	
Taken the hip cond tion into account n choice of occupation	33	33	5	15	2	11
later change in occupation	8	8	4	12	5	6
appl ed for rehabil tat on	21	21	6	18	1	5
obtained disablement pens n	1	1	(1)		5	6

Table 3 Social conditions One case in 35 group received pension for causes other than LCPD

Discussion Differences between the groups were merely an expression for their different possibilities according to changes and improvements in social legislation Allotment of pension and change in occupation was more frequent among the 65 group whereas the younger group had the opportunity to be helped in choice of occupation or for rehabilitation measures

Rejection for military service was stated in the following manner

Age group	25		35		65	
number of men	76		28		14	
rejection	57	75	17	61 %	10	71%

Table 4 Military service

Discussion Rejection must depend on traditions as the frequency of non fitness for service in the young groups far exceeded that of signs and symptoms for disablement

Finally questions were asked as to whether the patients from the 25 and 35 groups called to mind their prolonged stay in hospital as disagreeable

Age group		≦ 4		5—8		≧ 9	
all cases treated with bed rest	133	38	2J	67	50°	28	21°
recalled hospital stay as d sa reeable	1[illegible]	4	21°	8	4 %	5	29°

Table 5

Discussion 13 per cent (17 out of 133 patients) recollected their hospital stay as disagreeable One case recalled that it was disagreeable to come home

The 17 cases were distributed on the age groups approximately as the age groups on the whole material

Mobility	> 260		211—260		< 210	
no pain	83	79%	6	30%	3	11%
slight pain	16	15%	11	55%	8	31%
severe pain	6	6%	3	15%	16	59%
total 152	105		20		27	

Table 22 Secondary mobility related to secondary pain

Statistics Criterias of classification χ (4) = 69 5 p < 0 001 No independance between the two criterias of classification

Discussion There was found to be good correlation between on the one side mobility, and on the other side, radiological coxarthrosis and on pain at the follow up examination

Atrophy

Present Study

Atrophy was measured in centimetres at the level of the distal belly of the vastus medialis Differences above 2 centimetres were registered at the follow up examination in the **25** group in *18* cases (*18* per cent), in the **35** group in 5 cases (15 per cent) and in the **65**-group in 13 cases (68 per cent)

Within each of the three age groups the occurrence of atrophy at the follow up examination was compared to the primary shape and to the secondary occurrence of radiological coxarthrosis pain and mobility

In the **25** group atrophy was related to the primary occurrence of deformed heads (flattened ball shape + irregular heads) with possible significance

Likewise the **25** group showed accordance between secondary atrophy and secondary walking difficulties (possible signifiance)

For both the **35** and the **65** groups no statistical significant correlation of these parameters could be demonstrated Nor was atrophy in the **25**-group statistically correllated to any other parameters than the above mentioned

Discussion The **25** and **35** groups were both treated with bed rest followed by a period of walking with crutches and the diseased leg bound up in a Snyders sling It might have been expected that this ter*minal treatment had resulted in a severe* and long standing atrophy This was not the case In the two young groups atrophy occurred with equal frequency (18 and 15 per cent respectively), whereas the untreated group showed 68 per cent atrophy It seems, thus to be the degree of deformity and of coxarthrosis that determine the atrophy rather than the treatment

In the **25** group atrophy was correlated to primary shape of the head This finding was not repeated in the other groups, possibly caused by the small numbers in these samples

Functional capacity and ability to walk

Literature

Sundt (1949) mentioned lameness and limping in 31 cases among 149 examined for this matter In the rest of the cases impairment of functional capacity was imperceptible

Danielsson (1964) used the walking distance *together with other parameters in* an accumulated index for functional capacity This index was set up for the assessment of severe coxarthrosis in old age groups

Present Study

An attempt was made to code the present cases into a scheme for functional capacity like that of Danielsson However nearly all cases fell into the best groups with an absence of overflow to other groups which made statistical comparisons impossible

For that reason it was attempted to extract the walking ability alone It was arranged in *three groups* according to a procedure of estimation resembling that for pain and mobility

Discussion The results of this study were so close to the findings concerning radiological coxarthrosis pain and mobility that it was found needless to repeat the same conclusions regarding on the one hand walking disability and on the other 1) lack of treatment (65 group) 2) high age group at commencement of treatment 3) primary shape of the head and 4) severe secondary radiological coxarthrosis

Social conditions

A brief history of social and allied conditions was taken in all cases They could be outlined in a scheme as follows

	25	35	65
Taken the hip condition into account in choice of occupation	33 33	5 15	2 11%
later change in occupation	8 8	4 12 %	5 26
applied for rehabilitation	1 1	6 18	1 5
obtained disablement pension	1 1	(1)	5 6

Table 93 Social conditions One case in 35-group received pension for causes other than LCPD

Discussion Differences between the groups were merely an expression for their different possibilities according to changes and improvements in social legislation Allotment of pension and change in occupation was more frequent among the 65 group whereas the younger group had the opportunity to be helped in choice of occupation or for rehabilitation measures

Rejection for military service was stated in the following manner

Age group	25	35	65
number of men	6	28	14
rejection	57 75	17 61	10 71

Table 94 Military service

Discussion Rejection must depend on traditions as the frequency of non fitness for service in the young groups far exceeded that of signs and symptoms for disablement

Finally questions were asked as to whether the patients from the 25 and 35 groups called to mind their prolonged stay in hospital as disagreeable

Age group		≦ 4	5—8	≧ 9
all cases treated with bed rest	133	38 29 %	67 50	28 21%
recalled hospital stay as disagreeable	17	4 24	8 47	5 29

Table 95

Discussion 13 per cent (17 out of 133 patients) recollected their hospital stay as disagreeable One case recalled that it was disagreeable to come home

The 17 cases were distributed on the age groups approximately as the age groups on the whole material

Mobility		> 260		211—260		< 210
no pain	83	79%	6	30%	3	11%
slight pain	16	15%	11	55%	8	31%
severe pain	6	6%	3	15%	16	59%
total 152	105		20		27	

Table 22 Secondary mobility related to secondary pain

Statistics Criterias of classification χ^2 (4) = 69.5 p < 0.001 No independance between the two criterias of classification

Discussion There was found to be good correlation between on the one side mobility and on the other side, radiological coxarthrosis and on pain at the follow up examination

Atrophy

Present Study

Atrophy was measured in centimetres at the level of the distal belly of the vastus medialis Differences above 2 centimetres were registered at the follow up examination in the **25** group in 18 cases (18 per cent), in the **35** group in 5 cases (15 per cent) and in the **65** group in 13 cases (68 per cent)

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Danielsson (1964) used the walking di stance together with other parameters in an accumulated index for functional ca pacity This index was set up for the assessment of severe coxarthrosis in old age groups

flattened ball shaped heads had up to the present examination of the samples the same good prognosis as had the normal ball shapes

b) irregular shapes had a very high frequency of secondary troubles

10 The above statement (9 a) might be explained by the fact that primarily 'ball shaped heads according to the present definitions and methods turn to normal ball shape during growth from primary healing up to adult age (Tab 1)

11 The clinical examination of mobility showed that

a) rotations were the characteristic and first direction of movement to be reduced

b) atrophy was rare in the young groups even if they had been finally treated with a period of weight bearing on one leg Atrophy was frequent in the 65 group with its high incidence of irregular heads with coxarthrosis

12 Treatment The primarily untreated **65** group showed a significantly higher frequency of severe coxarthrosis and late troubles than did the **25** and **35** groups that were consistently relieved from weight bearing during the active phases of the disease

GENERAL CONCLUSIONS

The present three samples of LCPD were reexamined at a mean of 25 and 35 years (primarily treated) and 65 years (untreated) of age

The two former samples were comparable concerning composition of *sex* and *stage* at time of diagnosis

A slight difference in *age* at onset of treatment was eliminated by combining the two groups in the comparisons

The following could be concluded

1 At 25 as well as 35 years of age a very low frequency of severe radiological coxarthrosis was found (less than 6 per cent) (Tab 2)

2 The 65-group was untreated It comprised a very high percentage of irregularely healed heads The frequency of severe radiological coxarthrosis was above 85 per cent

3 At 25 and 35 years of age the occurrence of radiological coxarthrosis was nearly equal as regards the whole group (Tab 2)

Regarding only the irregularly healed heads in the same two groups a possible significant rise in occurrence of coxarthrosis was demonstrated during the decade from 25 to 35 years (Tab 6)

4 Severe pain was recalled to have started partly from the time of primary healing (before the age of 10) partly during the decades from 20 to 40 years of age (Tab 14)

The irregularly healed heads showed a possibly significant rise in occurrence of pain from the age of 25 to 35 (Tab 12)

Thus, the *secondary* coxarthrosis' arose 20 to 30 years before the pain at *primary* coxarthrosis, according to the statements of Ruelle

5 A few normal (and flattened) ball shaped cases complain of pain (tab 12) and show slight restriction of mobility (Tab 20)

This may be due to chance However, possibly other unknown factors than purely mechanical may play a role in the development of disablement in a few cases Slight fissures in the cartilage are supposed to give rise to the beginning of coxarthrosis Such slight fissures might be supposed to be the result of the primary deformation in some cases

6 *Sex* played no role for the late clinical or radiological result in the present samples

7 The *stage* at onset of treatment gave no reflection on the late results

8 *Age* of the child at establishment of diagnosis and treatment had a significant influence on late occurrence of radiological coxarthrosis pain and mobility

The younger the patients the better the late results

9 *Primary shape* of the head had a significant influence on the late occurrence of radiological coxarthrosis pain and mobility

a) primary normal versus flattened ball shaped heads showed no significant difference in late complications Thus

REFERENCES

Ahlback S O (1971) Klassifikation av hoftledsartros Nord Med 85 157–158

Brotherton B J & B Mc Kibbin (1977) Perthes Disease treated by prolonged re cumbency and femoral head containment a long term appraisal J Bone Jt Surg 59 B 8–14

Caterall A (1972) Coxa Plana Modern Trends in Orthop 6 122–147

Danielsson L G (1964) Incidence and Prognosis of Coxarthrosis Acta Orthop Scand suppl 66 14–20

Danielsson L G (1965) Late Results of Perthes Disease Acta Orthop Scand 36 70–81

Eaton G O (1967) Long term results of treatment in coxa plana J Bone Jt Surg 48 A 1031–1042

Evans D L (1958) Legg Calve Perthes Disease A study of late results J Bone Jt Surg 40 B 168–181

Gower W E U R C Johnston (1971) Legg Perthes Disease Long Term Fol low Up of Thirty six Patients J Bone Jt Surg 53 A 759 768

Helbo S (1953) Morbus Calve Perthes Specielt med henblik på behandlingen

Lauritzen J (1975) Legg Calve Perthes Disease A comparative study

Meyer J (1966) Treatment of Legg Calve Perthes Disease Acta Orthop Scand suppl 86

Meyer J (1977) Legg Calve Perthes Disease Radiological Results of Treatment and Their Late Clinical Consequences Acta Orthop Scand Suppl 167

Mose K (1964) Legg Calve Perthes Disease A comparison between three me thods of conservative treatment

Møller P E (1924) Malum Coxae Infan tilis

Ratliff H C (1967) Perthes Disease A study of thirty four hips observed for thirty years J Bone Jt Surg 49 B 102–107

Ruelle M (1961) La Coxarthrose Etude de 1000 dossiers radio cliniques J Belge de Med Physique et de Rhumatologie 16 113–123

Steinhauser E (1971) Spatergebnisse der perthesschen Krankheit Z Orthop 107 558–576

Sundt H (1949) Malum Coxæ Calve Legg Perthes With special regard to the prognosis and treatment Acta Chir Scand Suppl 148

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RHAGNAR MYRHAGE

Microvascular Supply of Skeletal Muscle Fibres

A microangiographic, histochemical and intravital microscopic study of hind limb muscles in rat, rabbit and cat

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From the Laboratory of Experimental Biology (Head. Professor P I Brånemark)
Department of Anatomy and the Department of Orthopaedic Surgery II (Head
Professor B. Stener) University of Göteborg Sweden

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By

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GÖTEBORG 1977

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INTRODUCTION

Skeletal muscles are composed of muscle fibres with differing speed of contraction fibre diameter and metabolism Slow contracting fibres have a higher activity of oxidative enzymes but usually a smaller diameter than *fast* contracting fibres (Eccles *et al* 1958 Dubowitz & Pearse 1960) Most muscles contain both slow and fast fibres and it has been suggested that the amount of each type of fibres is related to the anatomical position and the functional utilization of each muscle Anti-gravitation muscles which are situated deep within a muscle group have a higher percentage of slow fibres than superficially located muscles This interrelationship has been found in several laboratory animals (Ariano *et al* 1973) as well as in man (Edgerton *et al* 1975)

The maximal blood flow capacity is 2-3 times higher in slow muscles (e g the soleus) than in fast muscles (e g the gastrocnemius) - for a review see Hudlická (1973) While the arrangement of large intramuscular vessels (Spalteholz 1888 Hammersen 1964) and the amount of vessel anastomoses (Saunders *et al* 1957 Stingl 1973) seem to be similar in the two types of muscles the capillary network is denser in slow muscles than in fast muscles (Ranvier 1874 Romanul 1965 Cotter 1975) Differences in blood-flow characteristics and reactive hyperaemia have also been suggested (Gray 1971 Burton & Johnson 1972)

Endurance exercise increases the muscle fibre diameter but also the activity of oxidative enzymes in the fibres (Holloszy *et al* , 1971) The number of capillaries is enhanced parallel to the fibre hypertrophy but there is no change in the number of capillaries per mm^2 of muscle tissue (Hermansen & Wachtlová 1971)

REVIEW OF THE LITERATURE

CLASSIFICATION OF MUSCLE FIBRES

Skeletal muscles were first distinguished by their differences in pigmentation and content of lipid droplets as *white* and *red* (see review by Close 1972) The white muscles are *fast* contracting while the red are *slow* contracting as shown e g by Denny-Brown (1929) Histochemical analyses of the enzyme activity in muscle fibres have later revealed that most skeletal muscles contain three separate types of fibres

Table 1

CLASSIFICATION OF MUSCLE FIBRES

	Fast twitching		Slow twitching
Dubowitz & Pearse (1960)	II	(II)	I
Brooke & Kaiser (1970)	IIB	IIA	I
Henneman & Olson (1965)	A	B	C
Burke *et al* (1971)	FF	FR	S[1]
Peter *et al* (1972)	FG	FOG	SO[2]
	(white)	(red)	(red/intermediate)

[1] FF = fast-fatigable, FR = fast-resistant to fatigue
S = slow-very resistant to fatigue
[2] FG = fast-glycolytic FOG = fast-oxidative-glycolytic
SO = slow-oxidative

Originally these types of fibres were called white intermediate and red (e g Ogata 1958) When it was found that only the intermediate fibres have a slow contraction pattern the terminology was revised to fast-twitch white slow-twitch intermediate and fast-twitch red (Barnard *et al* 1971)

In clinical practice fast and slow contracting muscle fibres have usually been recognized as type II and type I respectively (Table 1) Subgroups of type

The motor neurons are assumed to have some trophic influence on the muscle fibre metabolism (Guth, 1968) If the motor nerves to a slow' and to a 'fast muscle are sectioned and then resutured in *reversed* position (cross,innervation), a parallel change of the fibre metabolism and the capillary density will follow (Romanul & Pollock, 1969) Similarly, the number of capillaries and the oxidative capacity of fast muscles will be increased when the intact motor nerve is intermittently stimulated for more than 4 days, with an impulse frequency naturally occurring in the nerves to slow muscles (Pette *et al* 1973 Brown *et al* 1976) This method of intensifying the muscle activity is usually referred to as chronic or long-term stimulation In contrast to muscle exercise, it does not cause fibre hypertrophy, but there is still an increased capillary density Furthermore, the chronically stimulated fast muscle gains several features characteristic of a slow muscle (Hudlická *et al* 1977)

It has been questioned whether the vascular architecture and the muscle fibre population is different in very thin and extended muscles as compared to thicker, polygonal or fusiformed muscles Doubts have also been raised concerning the existence of actual capillary growth in muscles subjected to chronic stimulation These problems will be elucidated in the present investigation which deals with angiographic intravital microscopic and histochemical analyses of the relationship between the peripheral vascular bed and the fibre population in hind limb muscles

ical identification via PAS-staining in combination with e g staining for SDH activity (Table 2) With this technique it has been shown that muscle fibres belonging to the same motor unit are histochemically identical (Edstrom & Kugelberg 1968, Burke & Tsairis 1973) The motor units vary in their speed of contraction and their sensitivity to fatigue and Burke *et al* (1971 1973) therefore described the three categories of muscle fibres as fast contracting - fast fatigable fast contracting - resistant to fatigue and slow contracting - very resistant to fatigue (Table 1) These terms were considered to be less confusing as compared to white and red" fibres (since both of these types of fibres are fast contracting) and to type II and type I or A B C fibres (since this nomenclature is also used for nerve fibres)

Peter *et al* (1972) quantified the glycogen concentration and the activity of several enzymes in muscles dominated by a single type of muscle fibres It was suggested that the fast-twitch white fibres (the nomenclature by Barnard *et al* 1971) should be called *fast-twitch-glycolytic FG*, since they were found to have a very high anaerobic capacity (high glycogen concentration and high activity of glycolytic enzymes) and a low aerobic capacity (low cytochrome concentration and SDH activity) The fast-twitch red fibres were found to have a moderate to high anaerobic as well as high aerobic capacity (very high cytochrome concentration and SDH activity) and they were therefore called *fast-twitch-oxidative-glycolytic FOG* The slow-twitch intermediate fibres had a low anaerobic and a moderate to high aerobic capacity and the name *slow-twitch-oxidative SO* was suggested (see Tables 1 and 2)

Some investigators have also described subgroups of FG and FOG fibres (Romanul 1964 Schmalbruch & Kamieniecka 1975) and of SO fibres (Askanas & Engel 1975) These findings might be due to individual enzyme activities in muscle fibres belonging to the same type of fibres (cf Nolte & Pette 1972)

II fibres (II A and II B) were described by Brooke & Kaiser (1970) from studies of the actomyosin ATPase activity at various pH levels (Table 2)

A third system of nomenclature has been used by e g Henneman & Olson (1965) and Kugelberg & Edström (1968), by which the white, red and intermediate fibres are called A, B, and C, respectively These terms might, however, cause confusion since other investigators (e g Stein & Padykula, 1962) designate intermediate fibres as B and red fibres as C

Repetitive stimulation of the muscle fibres innervated by a single motor neuron will result in depletion of the glycogen content in these muscle fibres The whole motor unit is then accessible for histochem-

Table 2

HISTOCHEMICAL STAINING INTENSITY AND METABOLISM OF MUSCLE FIBRES

Enzymes		FG	FOG	SO
SDH[1] NADH$_2$ - diaphorase[2]				
Mitochondrial α-GPDH[3] PAS[4]				
ATPase[5]	pH 9 4			
	pH 4 7			
Metabolic capacity	aerobic	low	high	moderate / high
	anaerobic	very high	moderate / high	low

[1] SDH = succinate dehydrogenase
[2] NADH$_2$ - diaphorase is oxidizing the co-enzyme NADH2 (nicotinamide-adenine dinucleotide) to NAD
[3] GPDH = glycerophosphate dehydrogenase
[4] PAS = periodic acid - Schiff test (for glycogen content)
[5] ATPase = adenine triphosphatase

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VASCULAR ARCHITECTURE AND CAPILLARY DENSITY IN SKELETAL MUSCLE TISSUE

Qualitative studies of injection specimens have revealed a *primary* and a *secondary* anastomosing vascular network, at the pre-capillary level, in skeletal muscles (Spalteholz, 1888, Krogh, 1922, Hammersen, 1964 Stingl, 1969) It was also stated by Spalteholz (1888) that most muscles contain numerous anastomoses Campbell & Pennefather (1919) postulated three different groups of muscles in man, according to the number of afferent muscle arteries and the pattern of intramuscular arterial anastomoses Classification of muscles in man has also been based on the vascular arrangement, together with the anatomical and functional features of the examined muscles (Saunders *et al* , 1957) From investigations of muscles in various animal species, Stingl (1973) emphasized that the pattern of vascular anastomoses is the optimal criterion for grouping of muscles with different vascular architecture Neither the review of the literature nor the observations in the study by Stingl revealed any correlation between the pre-capillary vascular arrangement and the fibre content in the examined muscles

However, several investigators have found that muscles dominated by FG fibres contain few straight capillaries, while muscles rich in SO fibres have numerous wide and sinusoidal capillaries (Ranvier 1874 Stoel 1925, Lee 1958 Romanul 1965)

Attempts have been made to quantify *the number of capillaries per mm^2 of muscle tissue* (see Hudlická 1973) The calculations were usually performed on cross-sections from muscles subjected to vascular perfusion of India ink The numbers of capillaries/mm^2 show a considerable divergence, which is usually interpreted to be a result of species differences but mainly caused by tissue shrinkage artefacts and unequivalent diameter of the FG FOG and SO fibres (see Table 2)

The number of capillaries per muscle fibre (also called *capillary/fibre ratio*) is independent of the tissue dimensions and therefore considered to be more representative for the capillary density Data of this type have also confirmed the difference in capillarization found by Ranvier (1874) and other investigators (see also review by Hudlická, 1973)

From histochemical staining of the capillary endothelium Romanul (1965) observed that the number of capillaries surrounding each muscle fibre was directly proportionate to the activity of oxidative enzymes in the fibres Plyley & Groom (1975) found no difference in the capillarization of muscle fibres with respect to the fibre metabolism In fact they stated that any differences in capillary density are primarily a consequence of differences in mean fiber size

AIMS OF THE PRESENT INVESTIGATION

1) To test the representativeness of the tenuissimus muscle for skeletal muscle tissue in general concerning the vascular architecture and the capillary supply of the muscle fibres The thin cat tenuissimus was compared with thicker hind limb muscles of the cat (the dorsal part of the biceps femoris the gastrocnemius - both heads separately - and the soleus) in the following respects
   a muscle anatomy and vascular architecture (I)
   b evaluation of the muscle fibre population and the capillary supply of fibres with differing diameter and metabolism (II)

2) To develop a method suitable for intravital studies of skeletal muscles subjected to various levels of activity The rat extensor hallucis proprius (EHP) was selected as experimental muscle (III)

3) To quantify the total capillary surface area and search for direct evidence of growing capillaries in chronically stimulated rabbit tenuissimus and rat EHP muscles (IV)

METHODOLOGICAL CONSIDERATIONS

GENERAL

Combined structural and functional studies have been found necessary for analyses of the regulatory mechanisms involved in the blood flow distribution in skeletal muscle This type of experimental approach is possible by intravital microscopy, but these *in situ* observations with transmitted light are limited to thin muscles (III)

The vasculature of thicker muscles can be analysed in injection specimens With radiographic technique it is possible to visualize the whole vascular tree, and even extramuscular vessels (cf Saunders *et al* , 1957) The main disadvantage of this method is the poor resolution of the microvascular bed even if radiopaque injectants with minimal particle size and viscosity are used The microvessels can, however, be studied satisfactorily after Indian ink perfusion and clarifying of the muscle according to the method of Spalteholz (1888 1911 see also Romeis, 1948) A certain degree of tissue shrinkage is unavoidable and to reach the deeper parts of the muscle belly, the specimens have to be sectioned From consecutive serial sections it is possible to reconstruct the whole intramuscular vessel tree with reasonable accuracy

Measurements of vessel dimensions can be carried out during intravital microscopy With controlled physiological conditions these figures would also be representative, since the vascular tone is preserved (cf Baez 1969 Eriksson, 1972)

For quantification of the capillary density in skeletal muscle tissue, conventional histological technique with formalin fixation should be avoided because of the tissue shrinkage artefacts Dye perfusion of the vascular bed is also unreliable since filling of the capillary network is usually incomplete (cf Plyley and Groom 1975 see also Hudlická 1973)

A preferable method is freeze fixation cryostat sectioning and histochemical staining for alkaline phosphatase activity (Gomori 1939 Pearse 1968) This enables specific identification of the endothelium in all capillaries present in the section, with the degree of tissue shrinkage kept to a minimum

Correlation of the capillary density to the muscle fibre population is important for a complete understanding of the nutritional characteristics of skeletal muscle tissue Various methods for histochemical staining of the enzyme activities in muscle fibres have been described (see review by Khan, 1976) With this technique it has been possible to evaluate the capacity of glycolytic oxidative and lipolytic enzymes in different muscle fibres Quantification of the cross-sectional area or mean diameter of the fibres can also be performed (cf Edström and Torlegaard 1968/69 Cotter *et al* 1973) since the linear dimensions of the tissue are fairly well preserved with careful freeze fixation

The fibre mass of skeletal muscles is grouped in fibre bundles (Figs 1 and 5) As a constant pattern most of the large glycolytic FG fibres are located close to the border of this bundle Thus, evaluation



Fig 1 Muscle fibre bundle (indicated by arrows) in the biceps femoris Corss section histochemically stained for the activity of alkaline ATPase according to the method described by Padykula & Herman (1955)

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After the perfusion all animals were divided at the lumbo-sacral level The skin was stripped off from the hind part of the body which was then fixed in 10% buffered formalin for 7 days Serial sections 500 µm thick were cut (perpendicularly and longitudinally to the direction of the muscle fibres) from the proximal the central and the distal part of each examined muscle (I) The tenuissimus muscles (IV) were thin enough to be examined without sectioning

After preparation of the muscle specimens (ad modum Spalteholz) the distinctly delineated vessel tree could be analysed in a 3-D microscope Comparative measurements of the vascular segments were carried out with an optical micrometer By using a phase contrast condenser in a Leitz Orthoplan microscope it was also possible to study the connective tissue around different parts of the vessel tree (I)

The arrangement of large nutritive vessels to the muscle belly (I) was studied by radiography after intravascular perfusion of 500 ml of a 50% saline suspension of barium sulphate (0 4 g/ml, Micobar[R] Astra Sweden)

HISTOCHEMISTRY

Fixation of the muscle specimens was performed in propare-propene (II), and in isopentane which was cooled in liquid N_2 (III and IV) Serial sections 7-10 µm thick were cut in a cryostat perpendicularly to the direction of the muscle fibres For qualitative fibre differentiation the sections were stained histochemically for the activity of $NADH_2$-diaphorase (Chayen *et al* , 1973) and alkaline (pH 9 4) actomyosin ATPase (Padykula and Herman 1955) In some experiments (III) the sections were stained for the activity of SDH (Nachlas *et al* 1957) instead of $NADH_2$-diaphorase Both of these methods demonstrate the oxidative capacity of the individual muscle fibres (Khan 1976)

of the percentage of different types of muscle fibre as well as the number of capillaries per fibre should be based on entire muscle fibre bundles Randomized fields of the histological cross-section would be difficult to standardize and would most likely be less representative for the total fibre population

MATERIALS AND ANAESTHESIA

The cats (in I and II) were of both sexes and weighed about 2 5 kg During the experiments they were anaesthetized with i v injections of chloralose (50 mg/kg) after induction with ether

The analyses of chronically stimulated tenuissimus muscles (IV) were performed on New Zealand Red rabbits of both sexes, weighing 1 7-2 5 kg For implantation of electrodes they were anaesthetized with thiopentone sodium (100 mg/kg, i v) and during intravital microscopy (after terminated stimulation) with pentobarbitone sodium (30 mg/kg, i v)

Female Wistar rats weighing 130-150 g were used in III and IV These animals were anaesthetized with ether during the implantation of electrodes When they were subjected to intravital microscopy the anaesthesia was initiated with 1 5 mg of diazepam and then completed with pentobarbitone sodium (3-4 mg/100 g body weight), intraperitoneally

ANGIOGRAPHY

Via a cannula in the abdominal aorta the hind limbs of cats and rabbits were perfused with 500 ml of Indian ink, diluted with saline 1 1, after pre-perfusion with 300 ml of Perfadex[R] (Pharmacia Sweden) Papaverine (0 2 mg/kg) was added to induce maximal vasodilatation and the perfusion pressure was 13 3 kPa (100 mmHg) The purpose of the pre-perfusion was to wash out blood cells and plasma as far as possible Ink particles have been found to form aggregates in contact with plasma proteins (Brånemark *et al* 1968) and any such aggregates would interfere with the filling of the microvessels

rabbits the venous blood pressure was measured via a cannula in the small saphenous vein

The peripheral vascular bed was studied *in vivo* (III and IV) using Leitz Intravital microscopes (Biomed and Large model, Leitz-Wetzlar W Germany The Large microscope was modified for high resolution recordings by Lab Exp Biology Göteborg)

Objectives (UO x11 NA 0 25 UO x23, NA 0 55 UO x55 NA 0 84) giving a magnification of up to x660 were used A heat-absorbing green filter (maximal transmission at 5500 Å) was used to minimize the influence of light on the tissue during the observation period

Recordings of the terminal arterioles, the capillary bed and the collecting venules were made with the microscope connected to a closed circuit TV system with a video tape recorder (see IV) Photographic registrations were made on Kodak Monochrome film (SO 410) with a Leitz System camera in the Biomed microscope and a Nikon F camera (Nippon Kogaku Japan) in the Large microscope Additional cinematographic documentation was performed in the Large microscope (see IV)

EVALUATION OF FIBRE POPULATIONS AND THE CAPILLARY BED

From each series of muscle sections 10 entire muscle fibre bundles were analysed (see I) This corresponds to about 400 muscle fibres By comparing photographs from serial sections alternatively stained for the activity of $NADH_2$-diaphorase (or SDH) and alkaline actomyosin ATPase different fibre types (FG,FOG,SO or A,B,C) could be distinguished and quantified Fibre diameters were calculated by taking the mean of 4 polygonal diameter measurements on each of the studied fibres in calibrated photographs (Cotter *et al* 1973)

The number of capillaries/muscle fibre in 20 adjacent fibre bundles (approximately 6000 μm^2 in rat EHP) was calculated in each series of sections The number of capillaries surrounding each individual muscle fibre was also registered in II, while the number of capillaries per mm^2 of muscle tissue was calculated for evalu-

The capillaries were visualized by a modified Gomori (1939) method for alkaline phosphatase (IV) and by the method of unspecific alkaline ATPase, as described by Guth and Samaha (1969,1970) - II, III, and IV

CHRONIC MUSCLE STIMULATION

Rabbit tenuissimus and rat EHP muscles were chronically stimulated for 8 h/day during 6-14 days (IV)

Stainless steel electrodes were implanted, under aseptic conditions, in the vicinity of the common peroneal nerve in rats To avoid extensive surgery of the tenuissimus muscles (supplied by a deep branch of the sciatic nerve), the electrodes were implanted onto the distal end of the muscle (about 2 cm distal to the area of intravital microscopy) The wires, led subcutaneously to emerge through the back of the animals, were connected by a flexible lead to conventional stimulators (Grass S8, and SD9) During stimulation (square wave pulses duration 0 3 msec, frequency 10 Hz)* the animals were allowed to move freely in their cages (cf Salmons and Vrbová, 1969 Pette *et al* 1973 Brown *et al* , 1976) The stimulation intensity (usually 3-6 V) was adjusted to evoke maximal contraction of the muscles, but it was kept low enough to avoid discomfort to the animals

For control of the operation trauma, one group of rabbits were sham-operated (electrodes were implanted without subsequent stimulation) In rats the contralateral intact and unstimulated muscle served as control, while in rabbits the control muscles had to be taken from different animals to the stimulated ones

INTRAVITAL MICROSCOPY

The animals were breathing spontaneously via a tracheal cannula One of the carotid arteries was cannulated for continuous monitoring of the arterial blood pressure (transducer, Statham pen recorder, Devices) In

*Close to the normal di charge frequency for motor neurons innervating slow muscles (Eccles *et al* 1958)

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The number of capillaries/muscle fibre in 20 adjacent fibre bundles (approximately 6000 μm^2 in rat EHP) was calculated in each series of sections The number of capillaries surrounding each individual muscle fibre was also registered in II while the number of capillaries per mm^2 of muscle tissue was calculated for evalu-

ation of the total capillary surface area (TCSA) in III and IV

During analyses of the video tape recordings, obtained from intravital microscopy, the monitored image was projected onto the focusing glass of a camera obscura This gave a final magnification of about 3000 times The architecture of the microvascular tree was registered and the vessel dimensions were measured with a microgauge

The length of each capillary was measured from the point of which it branched off from the obliquely running terminal arteriole and downstream to its connection with another capillary to form an obliquely running collecting venule The internal capillary diameter was measured at both the arteriolar and the venular end of individual capillaries

Capillary surface area in rat muscles (III, and IV) was calculated using a combination of the data obtained from the *in vivo* observations (the dimensions of individual capillaries) and the histochemical analyses (capillary counts and total muscle dimension)

RESULTS AND COMMENTS

COMPARATIVE ANALYSES OF THE TENUISSIMUS AND THICKER HIND LIMB MUSCLES OF THE CAT

Anatomy of the muscles studied

The tenuissimus (also called abductor cruris caudalis, Crouch, 1969) is 12 - 14 cm long and about 0 4 cm wide It is a quadrilateral muscle only 0 1 - 0 6 mm thick (see Eriksson & Myrhage 1972) and has a wet weight approximately 0 25 g Originating on the coccygeal vertebra, the muscle runs on the medial side of the biceps femoris, close to its dorsal edge (Fig 2) and inserts on the flat tendon of the biceps as well as in the crural fascia The muscle fibres which are only 2 cm long and therefore interdigitated (Adrian 1925) are oriented parallel to the longitudinal axis of the muscle

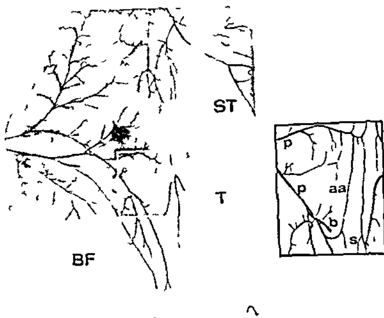


Fig 2 The biceps femoris muscle (BF) The tenuissimus (T) is slightly dislocated in the dorsal direction ST is the semitendinosus muscle Two *primary* arteries (p) are connected by an *arterio-arterial anastomosis* (aa) which is a little wider than the *secondary* artery (s) One of the primary arteries has a branch (b) which during the dissection was found to penetrate the muscle fascia into the subcutaneous tissue and the skin Full scale radiograph

The biceps femoris covers most of the lateral surface of the thigh This muscle is trilateral and considerably thicker than the tenuissimus The dorsal third of this muscle is distinctly thinner than the rest of the muscle belly This dorsal part of the muscle might be equal to the small head but in the literature on cat anatomy the two heads are usually not defined (cf Crouch 1969) The dorsal part which can be separated by blunt dissection has a wet weight of about 3 2 g The biceps muscle originates from the tuberosity of the isciadic bone and inserts on the lateral margin of the patella and the proximal third of the tibia The muscle fibres are oriented parallel to the longitudinal axis of the muscle

The lateral head of the gastrocnemius (LG) actually consists of three fusiformed beelies converging into a common sheet of the Achilles tendon Each belly has a separate origin, the small lateral one originates from the deep side of the biceps tendon, the central one from a sesamoid bone (fabella) on the dorsal side of the lateral condyle of the femur and the medial belly originates from the proximal part of the plantaris muscle Furthermore, the medial belly is fused (deep distally) with the plantaris muscle and (superficially) with the medial head of the gastrocnemius

The medial head of the gastrocnemius (MG) is a fairly flat muscle with a delicate origin on the medial fabella and the adjacent part of the medial condyle of the femur The insertion tendon is fused with the LG tendon These tendons together comprise the superficial part of the Achilles tendon, covering the insertion of the plantaris and the soleus muscles

The MG has a wet weight of about 7 4 g (the corresponding figure for the LG is 7 6) The muscle fibres of the LG are oriented parallel to the longitudinal axis of the muscle, while the MG fibres are attached to the dorsal muscle fascia and pass obliquely down to the ventral fascia

The soleus has a long fleshy origin on the lateral side of the proximal third of the fibula and inserts into the deep portion of the Achilles tendon The wet weight of this muscle is about 1 9 g The muscle fibres pass from the muscle origin obliquely down to the dorsal muscle fascia

Arrangement of the vascular tree (I)

The tenuissimus muscle contains one central artery (about 70 µm in diameter) and one or two central veins (diam , 90 µm) This group of vessels runs parallel to the orientation of the muscle fibres and usually has an uninterrupted course through the muscle *Terminal* arterioles (20 µm) and venules (40 µm) branch off from the central vessels in a two-dimensional pattern (Fig 3a) These vessels run transversely or

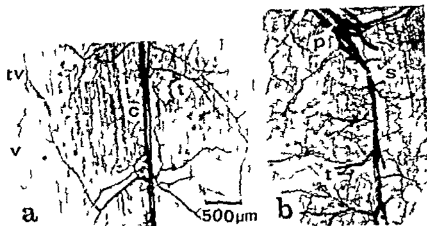


Fig 3 a) Spalteholz preparation of the *tenuissimus* muscle showing the central artery and vein (c) and transverse (terminal) arterioles and venules (t) A terminal venule (tv) runs close to the muscle fascia The vascular network (v) supplies fascia-embedded adipose tissue
b) Longitudinal section of the LG muscle prepared *ad modum* Spalteholz Obliquely running *primary* vessels (p) subdivide into *secondary* vessels (s) which give rise to terminal arterioles and venules (t)

obliquely to the muscle fibres and are in the periphery subdivided into capillaries which are oriented parallel to the direction of the muscle fibres

The central vessels of the tenuissimus correspond directly to the *secondary* generation of branches from the large intramuscular vessels in the biceps femoris (Fig 2) the LG (Fig 3b) and the MG as well as the soleus muscle

In these muscles the supplying arteries subdivide into a *primary* generation of branches (Fig 2) These vessels had a similar diameter range 150-350 µm The *secondary* arteries of thicker muscles were slightly wider (60-100 µm) than the corresponding vessels of the tenuissimus The endpoints of the *primary* arteries were interconnected by *arterio-arterial anastomoses* slightly wider (80-150 µm) than the *secondary* vessels (Fig 2)

Terminal arterioles branche off from the *arterio-arterial anastomoses* as well as the *secondary* arteries in a three-dimensional pattern The diameter range of the *terminal* arterioles was 25-40 µm i e they were a little wider than in the tenuissimus

The primary as well as the secondary veins follow the course of the corresponding arteries Duplicated *primary veins* are common only in the soleus muscle, while duplicated *secondary veins* occur both in the soleus and in the MG muscles

Terminal venules running close to the muscle fascia were found frequently in the tenuissimus muscle (Fig 3a) Such vessels were also found in the other muscles, especially in the MG

The average distance between secondary vessels was 1600-1800 µm in the biceps and the LG muscles, about 1200 µm in the MG, and 800-900 µm in the soleus The cross-sectional area of the tissue cylinder (Fig 4) supplied by one secondary artery in the MG muscle is about 1 mm^2 This value is in the range of the total cross-sectional area of the tenuissimus

Arterio-venous anastomoses were not observed at any level within the muscles examined This finding is in accordance with observations by Hammersen (1968) In the tenuissimus muscle however, several of the terminal vessels penetrate the epimysium and enter the surrounding connective tissue This type of vascular communication was also found in the other muscles e g in the biceps and the soleus, where some primary vessels penetrated the muscle fascia and supplied the subcutaneous tissue and the skin (Fig 2)

Both the tenuissimus and the biceps contain several anastomoses between the endpoints of the primary vessels This is a common feature of flat and extended muscles (Stingl, 1973) These anastomoses were less frequent in the LG muscle In the MG and the soleus, anastomoses were only seen connecting the largest of the primary vessel branches

The present investigation shows that *the vascular arrangement found in the tenuissimus muscle exists as a 'basic unit" in thicker muscles* (Fig 4) The terminal arterioles and venules which branch off from the secondary vessels in a three-dimensional pattern (two-dimensional in the tenuissimus) supply a cylinder of muscle fibres

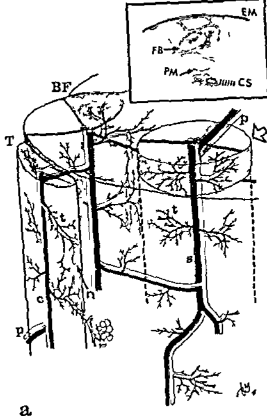




Fig 4 a) The vascular arrangement of the tenuissimus muscle (T) is found as a basic unit in thicker muscles (here represented by the biceps femoris BF) The terminal arterioles and venules (t) of this vascular basic unit are supplying the capillary network within a cylinder of muscle tissue (indicated by open arrow) p primary- c "central - and s= secondary vessels n= capillary network The fibre mass is first grouped by connective tissue septa (CS) and then subgrouped by two levels of perimysium (PM) enclosing the fibre bundles (FB) EM epimysium
b) Cross s ction of the biceps muscle clarified *ad modum* Spalteholz conventi nal condenser c) Phase contrast condenser

Such cylinders in the MG muscle have an average cross-sectional area which corresponds fairly well to the total area of a cross-section through the tenuissimus

Types of muscle fibres and capillary supply (II)
Freezing in liquid propane-propene preserves the skeletal muscle with a minimum of tissue artefacts Serial cryostat cross-sections stained alternately for $NADH_2$- diaphorase and alkaline ATPase permit a qualitative classification of types of muscle fibre (Fig 5)

The nomenclature used by Burke *et al* (1971) merely describes the functional characteristics of the muscle fibres (Table 1) The functional properties in relation to the histochemical staining pattern of individual motor units have been described in detail for the cat gastrocnemius muscle (Burke & Tsairis, 1973 Burke *et al* , 1973) It would therefore seem reasonable

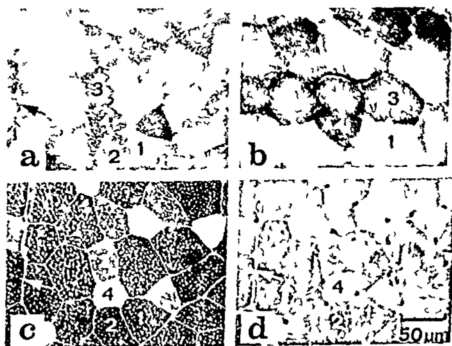


Fig 5 Cryostat sections of the LG (a c and d) and of the MG muscle (b) Histochemical staining for $NADH_2$-diaphorase activity (a and b) and alkaline ATPase activity ad modum Padykula & Herman (c) and Guth & Samaha (d) respectively 1 = FG 2 = FG/FOG 3 = FOG 4 = SO Arrows indicate the border-line of a muscle fibre bundle

to use the more explicit nomenclature of Peter *et al* (1972) which also indicates the metabolic capacity of each type of fibres The fast contracting fibres are either mainly glycolytic (FG) or both glycolytic and oxidative (FOG) and the slow contracting fibres are mainly oxidative (SO)

In accordance with the findings of Ariano *et al* (1973) the biceps femoris and the LG muscles were found to be dominated by FG fibres (40-50% of the total fibre population) The major part of all muscles in this study had a higher percentage of FOG fibres than was reported by Ariano This discrepancy might be due to different levels of exercise of the investigated animals since endurance training is known to increase the number of FOG fibres (Barnard *et al* 1970 Jansson & Kaiser 1977) In the present study the highest number of FOG fibres was found in the tenuissimus ruscle (45-50% of the fibres) The MG muscles had about 35% of SO fibres twice as much as the LG biceps femoris and tenuissimus The soleus consisted to almost 100% of SO fibres

Some fibres with high alkaline ATPase activity (which is typical for FG fibres) had a $NADH_2$-activity corresponding to the FOG fibres This intermediate type of fibre called FG/FOG fibres generally formed 10-15% of the fibre populations in the biceps femoris and the LG muscles A similar fibre type has been found in cat LG and tibialis anterior muscles by Hammarberg (1974)

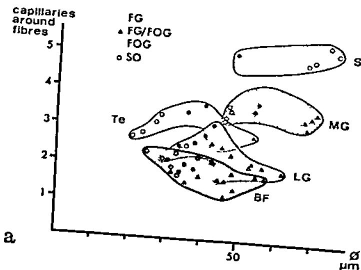
The MG and the soleus generally had larger fibres than the other muscles (Fig 5) The average fibre diameter reflects the contractile force of the muscle but is also influenced by the muscle fibre orientation In the MG and the soleus both ends of all fibres are attached to the epimysium (Burke & Tsairis 1973 Murphy & Beardsley 1974) Sections of these muscles perpendicular to the fibres thus contain few fibres which are cut close to the fibre endpoint The other muscles have fibres oriented parallel to the longi-

tudinal axis of the muscle the length of which exceeds the fibre length Consequently, these fibres are interdigitated and several of them will be cut close to the fibre end points in a muscle cross-section This would explain the low values of average fibre diameter found especially in the tenuissimus

The soleus muscles contained quite large SO fibres In the other three muscles studied, this type of fibre had a smaller average diameter than the fast contracting fibres The FG fibres were the largest fibres in all evaluated muscles, with the exception of the soleus which did not contain these fibres (Fig 6)

Endothelial cells have a high alkaline phosphatase activity (Gomori, 1939, Romanul, 1965) According to e g Freiman & Kaplan (1960) this enzyme is capable of hydrolyzing ATP, which is used as substrate in histochemical staining of ATPase activity In the present investigation the alkaline ATPase activity was examined with a histochemical method containing no blocking agent for alkaline phosphatase (Guth & Samaha, 1969, 1970) This enabled quantification of the different types of muscle fibres as well as the total number of capillaries in the same tissue section

Romanul (1965) suggested that the number of capillaries around each muscle fibre is directly correlated to the oxidative capacity of the muscle fibres It has later been stated that the fibre diameter is the only factor determining the capillarization of muscle fibres The present calculations revealed a fairly linear relationship between fibre size and number of fibre-surrounding capillaries for all types of muscle fibres However, the large FG fibres were surrounded by fewer capillaries than the smaller FOG and SO fibres (Fig 6) The values of capillaries around fibres were lower in all the biceps femoris and the LG muscles studied as compared to the tenuissimus muscles which in turn had lower values than the MG and the soleus muscles This difference in capillarization was confirmed by calculations of the capillary/muscle-fibre ratio



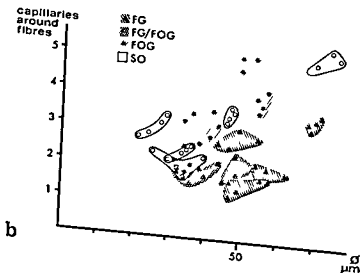


Fig 6 The average number of capillaries around individual muscle fibres in relation to fibre type and average diameter of the fibres (in four animals) a) values grouped for different muscles b) values grouped for different fibre types Te = the tenuissimus muscle BF = the biceps femoris LG = the lateral head and MG the medial head of the gastrocnemius S the soleus

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The EHP muscle is supplied by three small branches from the anterior tibial artery Most of the veins leave the proximal part of the muscle to the anterior tibial vein However three to four veins (30-50 µm in diameter) drain the distal part of the muscle to the deep fascia and into the tendon Usually the EHP contains one central artery about 30 µm in diameter and running parallel to the longitudinal axis of the muscle Proximally this vessel is accompanied by a vein (about 40 µm in diameter) which distally is a fusion of venous branches running close to the margins of the muscle Terminal arterioles and venules branch off in a pattern similar to that in the tenuissimus (Eriksson & Myrhage 1972) The capillaries have a few intercapillary branches The capillary blood-flow is intermittent with periods of varying flow and periods (10-60 sec) of circulatory arrest (cf Burton & Johnsson 1972) The average internal diameter of the capillaries is 4 0 µm at the arteriolar end and 5 5 µm close to the collecting venule Measured from the branching off from the terminal arteriole down to the collecting venule the average capillary length is 535 µm

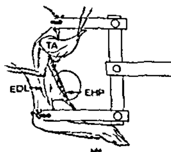


Fig 7 The EHP muscle exposed for intravital microscopy The lower leg of the rat is stabilized with a holder and the EHP muscle with intact deep fascia is placed on a glass cone and transilluminated Both of the adjacent muscles (extensor digitorum longus EDL and the tibialis anterior TA) are gently held aside

Thus *the capillary supply of muscle fibres seems to be directly proportional to the oxidative enzyme activity as well as th diameter of individual muscle fibres* The thin tenuissimus muscle does not differ from thicker muscles in this respect The comparably large number of capillaries in relation to the average fibre diameter in the tenuissimus can reasonably be explained by the high proportion of FOG fibres in this muscle

THE EXTENSOR HALLUCIS PPOPRIUS MUSCLE (EHP) OF THE RAT (III)

There seems to be no major discrepancies between the tenuissimus and thicker hind limb muscles of the cat as regards the architecture of the vascular bed and the capillary supply of the muscle fibres However, considering the point of insertion in relation to the knee joint, it is questionable whether the tenuissimus muscle acts primarily as a muscle of locomotion

Only the marginal parts of thick, fusiformed or polygonal muscles that are of importance for locmotion can be used for *in vivo* observations of skeletal muscle circulation (see Gray 1971) In the case of the fusiformed EHP muscle of adult rats even the belly is thin enough to be transilluminated for intravital microscopy

From its origin on the central part of the fibula and the interosseous membrane the EHP muscle runs parallel to the extensor digitorum longus on the deep side of the tibialis anterior muscle The tendons of the EHP and latter muscle pass together under the transverse crural ligament, whereafter the EHP tendon follows the medial side of the paw and inserts on the second phalanx of the first digit By dividing the ligament and the tendon of the tibialis anterior muscle the EHP can be held out ventrally and exposed for intravital microscopy (Fig 7) The major part of the vascular bed can be analysed with an adequate resolution

physiological characteristics of the nerve innervating the muscle is indicated from experiments on "cross-innervation (Romanul & Pollock 1969)

Chronic stimulation, at a low impulse frequency of the intact nerve to a fast muscle has a slowing effect on the speed of contraction Simultaneously the glycolytic enzyme activity decreases while the glucose phosphorylation and the fatty acid activation increase This is later followed by an increased oxidative capacity (Pette *et al* 1973) After 28 days of stimulation the histochemical fibre staining pattern in the fast muscle can not be distinguished from that of a slow muscle (Brown *et al* 1976)

In the chronically stimulated rat EHP muscle the percentage of glycolytic fibres (FG) decreased steadily with the time of stimulation Parallel to this there was an increase in the number of oxidative fibres (SO and FOG) which showed a slightly intesified staining for SDH activity as compared to the corresponding fibres in the control muscles The average diameter of FG fibres was smaller after stimulation while the dimensions of SO and FOG fibres were not changed (Fig 8) This is in accordance with observations from stimulated large rabbit muscles (Cotter *et al* 1973)

In vivo observations of the microvascular bed in stimulated muscles revealed an increased internal diameter of the capillaries This was most prominent in the tenuissimus muscles stimulated for 7 days where the average capillary diameter was 6 1 µm at the arteriolar and 9 5 µm at the venular end of the capillary as compared to 4 7 and 6 1 µm respectively in the control animal. It should be emphasized that these figures represent relative values But the differencies are real since the measurement error is the same

In the stimulated EHP muscles the increase in diameter of the capillaries was smaller but still detectable by the simple fact that the erythrocytes did not deform to the same extent during passage through

The muscle fibre mass of the EHP is dominated by fast glycolytic (FG) fibres (about 60%, average diameter 35 µm) Slow oxidative fibres (SO) constitute 15-20% (diam about 20 µm) and the rest of the fibres are of the FOG type (diam 25-30 µm)

The proximal cross-section of the muscle contains on average 1350 capillaries/mm^2, and close to the tendon the value is about 1050 The discrepancy might be explained by the decreased dimension of the muscle fibres as they insert into the tendon

The total capillary surface area (TCSA), as calculated from *in vivo* measurements of individual capillaries and histochemical data on capillary density and related to the total dimensions of the muscle amounts to an average value of 1 6 m^2/100 g of muscle tissue A considerably lower value of TCSA (0 7) was found by Pappenheimer *et al* (1951) in India-ink-perfused cat muscles Species differences, e g differing body size, might explain this discrepancy (Schmidt-Nielsen & Pennycuik, 1961) It should be noted, however that evaluations of capillary density from injection specimens may easily underestimate the total number of capillaries since it is difficult to fill all capillaries present in the tissue with this technique

The anatomy and the location of the EHP muscle is quite favourable for structural and functional *in vivo* analyses of the skeletal muscle circulation Being a well-defined locomotor muscle with a proper tendon the *EHP would be more suitable than the tenuissimus for studies of tissue nutritional adaptation to various levels of muscle activity*

CHRONIC STIMULATION OF THE RABBIT TENUISSIMUS AND THE RAT EHP MUSCLES (IV)

Postnatal differentiation of the muscle fibre metabolism and the vascular bed in skeletal muscles is closely connected with the functional activity of the muscles (Hudlická 1973) A direct correlation between the fibre metabolism the capillary density and the

Recent fusion of two sprouts was indicated by hour-glass-shaped capillary segments Erythrocytes were frequently observed being very slowly squeezed through these narrow passages A similar pattern of capillary growth has been described for the tadpole tail (Meyer 1853) the rabbit ear chamber (Clark & Clark, 1939 Cliff, 1963 Brånemark 1965 Lindhe & Branemark 1970) and for healing muscle wounds (Schoefl 1963, McKinney & Panner 1972) The proportion of sprouts to pre-existing capillaries was about 40% in both the tenuissimus and the EHP muscles after 14 days of stimulation This figure corresponds roughly to the values of increased capillary density found in stimulated rabbit muscles (Cotter *et al* , 1973 Brown *et al* 1976)

The newly formed capillaries often had a winding or tortuous appearance, similar to the capillaries normally found in slow muscles (Romanul 1965)

The total capillary surface area (TCSA) had an average value of 1 41 m^2/100 g of muscle tissue in the contralateral control muscles This value was in-



Fig 10 Capillary *sprout* in a rat EHP muscle stimulated for 12 days The sprout originates from a sharp bending of a pre-existing capillary (PC) and runs along the muscle fibres T is a trapped thrombocyte close to the tip of the *sprout* and E = two trapped erythrocytes Arrows indicate blood flow direction From 16 mm film

the capillaries in the stimulated as compared to the control muscles (Fig 9)

Growth of new capillaries in the stimulated muscles was observed as *buds* or *sprouts* going off from the bendings of the pre-existing capillaries The sprouts often contained trapped erythrocytes and thrombocytes, which showed small oscillatory movements (Fig 10)

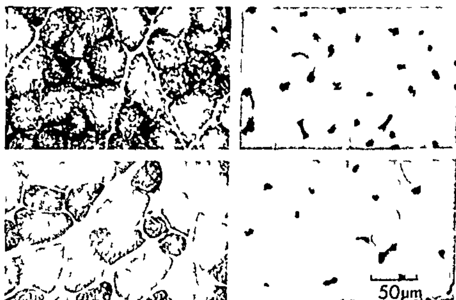


Fig 8 EHP muscle chronically stimulated for 7 days (above) and contralateral control muscle (below) Cryostat sections histochemically stained for SDH (left) and alkaline phosphatase activity (right)

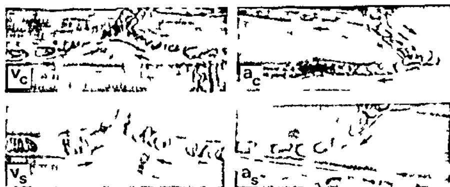


Fig 9 Arteriolar (a_c) and venular end (v_c) of a capillary in the contralateral *control* EHP muscle and corresponding parts (a_s and v_s) after 7 days of chronic *stimulation* Arrows indicate blood flow direction

Recent fusion of two sprouts was indicated by hourglass-shaped capillary segments Erythrocytes were frequently observed being very slowly squeezed through these narrow passages A similar pattern of capillary growth has been described for the tadpole tail (Meyer 1853), the rabbit ear chamber (Clark & Clark, 1939 Cliff 1963 Brånemark 1965 Lindhe & Brånemark 1970) and for healing muscle wounds (Schoefl 1963 McKinney & Panner 1972) The proportion of sprouts to pre-existing capillaries was about 40% in both the tenuissimus and the EHP muscles after 14 days of stimulation This figure corresponds roughly to the values of increased capillary density found in stimulated rabbit muscles (Cotter *et al* 1973 Brown *et al* 1976)

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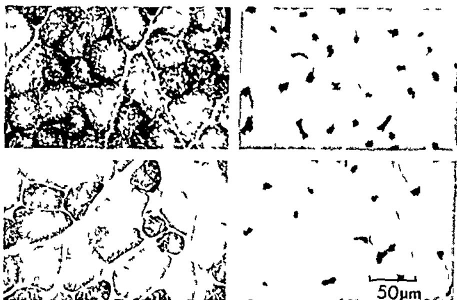


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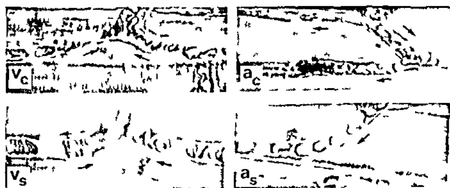


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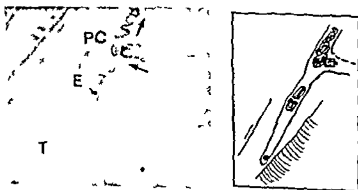


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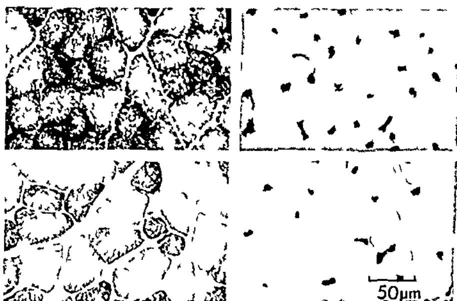


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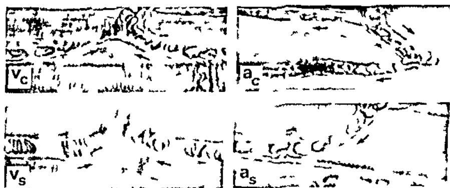


Fig 9 Arteriolar (a_c) and venular end (v_c) of a capillary in the contralateral *control* EHP muscle and corresponding parts (a_s and v_s) after 7 days of chronic *stimulation* Arrows indicate blood flow direction

Neither the diameter nor the metabolism of the muscle fibres not even the capillary/fibre ratio are changed in fast contracting muscles subjected to chronic stimulation at an impulse frequency *exceeding* 10 Hz Similarly, no changes in the fibre population or the capillary/fibre ratio of slow contracting muscles were found after chronic stimulation at 40 Hz - the impulse frequency normally occurring in nerves to fast muscles - (Brown *et al* , 1976)

It should be noted however that in the case of chronic stimulation an altered pattern of activity is *superimposed* on the normal motor nerve activity In cross-innervation the *total* activity of the motor nerve is altered which actually changes the metabolism and the number of capillaries even in slow contracting muscles (Romanul & Pollock, 1969)

In view of this the pattern of activity in the motor nerve seems to be more important than the level of muscle exercise as a regulating factor for the metabolism and the *capillary supply* of muscle fibres

COMMENTS ON VASCULAR INTERCONNECTIONS BETWEEN SKELETAL MUSCLES AND OTHER MESENCHYMAL TISSUES

The main trunks of about 30% of the "transverse" arterioles and venules regularly penetrate the fascia of the tenuissimus muscle and ramify into the deep extended part of the fascia (Fig 7) These vessels form a capillary network supplying the adipose tissue which is embedded in the fascia (cf Myrhage *et al* 1973)

Similarly 4-5 branches of primary arteries and veins were found to leave the belly of all examined biceps femoris muscles Careful dissection revealed that these vessels subdivided in the subcutaneous tissue adjacent to the muscle Such interconnecting vessels were also observed in the LG and the MG muscles where they however are smaller and less frequent

creased by 29% (1 81) in muscles stimulated for 7 days and by 46% (2 08) in muscles stimulated for 14 days

Factors connected with tissue injury, e g granulocyte-released substances (Branemark, 1965) and histamine (Smith 1961, Schoefl 1963), have been suggested as initiating capillary growth during tissue regeneration In the chronically stimulated muscles this type of stimulus is probably not present since histological examinations showed no signs of inflammation and mast cells were only occasionally observed in close vicinity to the sprouts Furthermore there was no change in capillary diameter and no capillary sprouts in the sham-operated tenuissimus muscles

Collagen which has been observed close to the tip of capillary sprouts might support the growth of new capillary segments (Cliff, 1963 McKinney & Panner, 1972) In the stimulated muscles we frequently found a bright wedge-like zone around the tip of the sprouts The location of this zone corresponds well to the site of the collagen fibres in the previous studies

It has been postulated by Ashton (1961) that endothelial cells are directly sensitive to oxygen and start multiplying at low oxygen levels A high capillary density has also been found in animals living continuously at high altitudes (Valdivia 1958) Increased muscle activity by prolonged contractions at 10 Hz seems to be associated with a considerable increase in oxygen consumption (Cotter & Hudlická unpublished data) Thus it cannot be excluded that chronic stimulation causes a relative hypoxia in the muscle during the first few days of stimulation which might provoke the gradual increase in TCSA

Endurance muscle training increases the diameter of the muscle fibres parallel to the number of capillaries per fibre (Hermansen & Wachtlova 1971) In contrast to this the muscle fibres have a smaller average diameter after chronic stimulation at 10 Hz but still an increased capillary/fibre ratio

evaluated as the number of fibre surrounding capillaries and as the number of capillaries per muscle fibre

A method was developed for intravital microscopy and estimation of the total capillary surface area (TCSA) of the rat extensor hallucis proprius muscle (EHP)

Blood flow distribution in the microvascular bed the structure of the capillary network and changes in TCSA were evaluated in chronically stimulated adult rabbit tenuissimus and rat EHP muscles

From the results the following conclusions are made

1 A vessel arrangement similar to that found in tenuissimus is present as a basic unit" even in the thicker hind limb muscles

2 The average cross-sectional area of this unit in the MG muscle is in the range of the total cross-sectional area of the tenuissimus (about 1 mm^2) This value is about 80% greater in the biceps femoris and the LG muscles but 50% less in the soleus

3 Generally all fibres in the MG are 20-40% larger than the corresponding fibres in the tenuissimus, the biceps and the LG The soleus has quite large SO fibres (about 70 µm in diameter) as compared to this type of fibre (25-45 µm) in the other muscles

4 Cat muscles with large muscle fibres have a higher number of capillaries per fibre (1-2) than muscles with a smaller average fibre diameter (relative value less than 1 capillary) In spite of a larger diameter the FG fibres are surrounded by fewer capillaries (1-3) as compared to the FOG and the SO fibres (2-4) It seems most likely that the oxidative capacity of the fibre is more important than the fibre diameter as a regulatory factor for the fibre capillarization

The main trunk of a primary artery penetrated the distal part of the soleus in about 75% of all the examined muscles This vessel (followed by two parallel primary vein branches) ramifies in the crural fascia and also gives branches to the periosteum of the tibia

Corresponding vascular interconnections have also been found in the lower leg of man (Saunders *et al* 1957) From investigations of injured rabbit EHP muscles, Zucman (1960) concluded that intact vascular anastomoses between muscle and periosteum are essential for successful revascularization of the muscle

Thus vascular interconnections between muscles and other mesenchymal tissues might be more important for the blood flow distribution than is generally appreciated

Intravital microscopy has been found quite suitable for investigations of these vascular pathways Pilot studies of EHP muscles, subjected to various periods of denervation indicate that vessels of this type are involved in the circulatory adaptation during muscle atrophy

SUMMARY AND CONCLUSION

Hind limb muscles from cats subjected to intravascular perfusion of India ink were prepared according to the method of Spalteholz The vascular tree in the unsectioned tenuissimus muscles was analysed and compared with the arrangement of vessels in sectioned thicker hind limb muscles (the biceps femoris the gastrocnemius - both heads separately and the soleus)

Quantification of different fibre types (FG FOG and SO) was performed in serial cryostat sections histochemically stained for the activity of $NADH_2$-diaphorase (or SDH) and alkaline ATPase The capillary endothelium was identified by staining for the activity of alkaline phosphatase and the capillary density was

evaluated as the number of fibre surrounding capillaries and as the number of capillaries per muscle fibre

A method was developed for intravital microscopy and estimation of the total capillary surface area (TCSA) of the rat extensor hallucis proprius muscle (EHP)

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5 The tenuissimus muscle does not differ from thicker muscles in respect of the vascular arrangement and the capillary supply of muscle fibres, although the tenuissimus seems to be of minor importance for locomotion

6 The rat EHP is a typical locomotor muscle and is also quite suitable for combined intravital and histochemical studies FG fibres dominate in this muscle The vascular bed has an arrangement similar to that of the tenuissimus However the capillaries have fewer interconnections, which is in advantage for evaluations of the TCSA

7 Chronic muscle stimulation of fast contracting muscles at 10 Hz results in widening of the capillaries especially close to the collecting venules The capillary density is also increased These rearrangements of the capillary bed enhance the TCSA in the rat EHP by 46% after 14 days of stimulation

8 Growth of new capillaries in the stimulated muscles was observed as *sprouts* emanating from pre-existing capillaries The proportion of sprouts to pre-existing capillaries is about 40% after 14 days of stimulation

REFERENCES

Adrian E D (1925) The spread of activity in the tenuissimus muscle of the cat and other complex muscles *J Physiol (Lond.) 60* 301-315

Ariano M A Armstrong R B & Edgerton V R (1973) *Hind limb* muscle fiber populations of five mammals *J Histochem Cytochem* 21 51-55

Ashton N (1961) Neovascularization in occular disease *Trans ophthal Soc U K* 81 145-161

Askanas V & Engel W K (1975) Distinct subtypes of type I fibers of human skeletal muscle *Neurology (Minneap)* 25 879 887

Baez S (1969) Simultaenous measurements of radii and wall thickness of microvessels in the anaesthetized rat *Circ Res* 25 315 329

Barnard R J Edgerton V R Furukawa T & Peter J B (1971) Histochemical biochemical and contractile properties of r d white and intermediate fibers *Amer J Physiol* 220 410 414

Barnard R J Edgerton V R & Peter J B (1970) Effect of exercise on skeletal muscle I Biochemical and histochemical prop rties *J appl Physiol* 28 762-766

B anemark P-I (1965) Capillary form and function The microcirculation of granulation tissue *Bibl anat (Basel)* 7 9 28

Branemark P-I Ekholm R & Lindhe J (1968) Colloidal carbon used for identification of vascular permeability *Med exp* 18 139-150

Brooke M H & Kaiser K k (1970) Muscle fiber types How many and what kind? *Arch Neurol (Chic)* 23 369-379

Brown M D Cotter M A Hudlicka O & Vrbova G (1976) The effects of different patterns of muscle activity on capillary density mechanical properties and structure of slow and fast muscles *Pflügers Arch* 361 241-250

Burke R E Levine D N Tsairis P & Zajac F E (1973) Histological types and histochemical profiles in motor units of the cat gastrocnemius *J Physiol (Lond)*234 723-748

Burke R E Levine D N Zajac F E Tsairis P & Engel W K (1971) Mammalian moto units Physiological - histochemical correlation in three types in cat gastrocnemius *Science* 174 709-712

Burke R E & Tsairis P (1973) Anatomy and innervation ratios in motor units of cat gastrocnemius *J Physiol (Lond)* 234 749-765

Burton K S & Johnsson P C (1972) Reactive hyperemia in individual capillaries of skeletal muscle *Amer J Physiol* 223, 517-524

Campbell J & Pennefather, C M (1919) An investigation into the blood supply of muscles with special reference to war surgery *Lancet* 1, 294-296

Chayen J Bitensky L & Butcher, R G (1973) *Practical histochemistry* pp 177-203 John Wiley & Sons London

Clark E R & Clark E L (1939) Microscopic observations on the growth of blood capillaries in the living mammal *Amer J Anat* 64 251-299

Cliff W J (1963) Observations on healing tissue A combined light and electron microscopic investigation *Phil Trans B* 246 305-325

Close R I (1972) Dynamic properties of mammalian skeletal muscles *Pharmacol Rev* 52 129-197

Cotter M (1975) *A study of the interrelationship between the vascular supply and metabolism of skeletal muscle fibres in the course of development and during chronic stimulation of adult muscles* Ph D Thesis Department of Physiology University of Birmingham U K

Cotter M Hudlicka O & Vrbova G (1973) Growth of capillaries during long-term activity in skeletal muscle *Bibl anat* (Basel) 11 395-398

Crouch J E (1969) *Text-atlas of cat anatomy* Lea & Ferbiger Philadelphia

Denny-Brown D E (1929) The histological features of striped muscle in relation to its functional activity *Proc roy Soc B* 104 371-411

Dubowitz V & Pearse A G E (1960) A comparative histochemical study of oxidative enzyme and phosphorylase activity in skeletal muscle *Histochemie* 2 105-117

Eccles J C Eccles R M & Lundberg A (1958) The action potentials of the alpha motorneurones supplying fast and slow muscles *J Physiol (Lond)* 142 275-291

Edgerton V R Smith J L & Simpson D R (1975) Muscle fibre type populations of human leg muscles *Histochem J* 7 259-266

Edstrom L & Kugelberg E (1968) Histochemical composition distribution of fibre and fatiguability of single motor units *J Neurol eurosurg Psychiat* 31, 424-433

Edstrom L & Torlegaard K (1968/69) Area estimation of transversely sectioned muscle fibres *. ches Mikr* 69 166-178

Eriksson E (197) *Microcirculation in skeletal muscle in cat* Ph D Thesis Lab Exp Biology Department of Anatomy University of Goteborg Sweden

Eriksson E & Myrhage R (1972) Microvascular dimensions and blood flow in skeletal muscle *Acta physiol scand* 86, 211-222

Freiman D G & Kaplan N (1960) Studies on the histochemical differentiation of enzymes hydrolyzing adenosine triphosphate *J Histochem Cytochem* 8 159-170

Gomori G (1939) Microtechnical demonstration of phosphatase in tissue sections *Proc Soc exp Biol (N Y)* 42 23-26

Gray S D (1971) Responsiveness of the terminal vascular bed in fast and slow muscles to α-adrenergic stimulation *Angiologica* 8 85-296

Guth L (1968) Trophic influences of nerve on muscle *Physiol Rev* 48 6 5-687

Guth L & Samaha F J (1969) Qualitative differences between actomyosin ATPase of slow and fast mammalian muscle *Exp Neurol* 25 138-152

Guth L & Samaha F J (1970) Procedure for the histochemical d monstration of actomyosin ATPase *Exp Neurol* 28 365-367

Hammarberg C (1974) Histochemical staining patterns of muscle fibres in the gastrocnemius soleus and anterior tibial muscles of the adult cat as viewed in serial sections stained for lipids and succinic dehydrogenase *Acta neurol scand* 50 ?72-?84

Hammersen F (1964) Das Gefassmuster der Skeletmuskulatur In *Probleme der Haut- und Muskeldurchblutung* eds L Delius and E Witzleb pp 11-26 *(Bad Oeynhausener Gesprache VI)* Springer Berlin

Hammersen F (1968) The pattern of the terminal vascular bed and the ultrastructure of capillaries in skeletal muscle In *Oxygen transport in blood and tissue* eds D-W Lubbers V C Luft G Thewe and E Witzleb pp 184-197 and 258-261 George Thieme Verlag Stuttgart

Henneman E & Olson C B (1965) Relations between structure and function in the design of skeletal muscles *J Neurophysiol* 28 581-598

Burke R E Levine D N Zajac, F E Tsairis P & Engel W K (1971) Mammalian moto units Physiological - histochemical correlation in three types in cat gastrocnemius *Science* 174 709-712

Burke R E & Tsairis P (1973) Anatomy and innervation ratios in motor units of cat gastrocnemius *J Physiol (Lond)* 234 749-765

Burton K S & Johnsson P C (1972) Reactive hyperemia in individual capillaries of skeletal muscle *Amer J Physiol* 223, 517-524

Campbell, J & Pennefather C M (1919) An investigation into the blood supply of muscles with special reference to war surgery *Lancet* 1 294-296

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Eccles J C Eccles R M & Lundberg A (1958) The action potentials of the alpha motorneurones supplying fast and slow muscles *J Physiol (Lond)* 142 275-291

Edgerton V R Smith J L & Simpson D R (1975) Muscle fibre type populations of human leg muscles *Histochem J* 7 259-266

Nolte J & Pette D (1972) Microphotometric determination of enzyme activity in single cells in cryostat sections II Succinate dehydrogenase lactate dehydrogenase and triosephosphate dehydrogenase activities in red intermediate and white fibres of soleus and rectus femori muscles of rat *J histochem Cytochem* 20 577-582

Ogata T (1958) A histochemical study of the red and white muscle fibres Part III Activity of the diphosphopyridine nucleotide diaphorase and trip osphopyridine nucleotide diaphorase in muscle fibers *Acta Med Okayama* 12 233-240

Padykula H A & Herman E (1955) The specificity of the histochemical method for adenosine triphosphata e *J Histochem Cytochem* 3 170-195

Pearse A G E (1968) *Histochemistry Theoretical and applied* vol 1 J & A Churchill Ltd London

Peter J B Barnard R J Edgerton V R Gillespie C A & Stempel K E (1972) Metabolic profiles of three fibre types of skeletal mus le in guinea pigs and rabbits *Biochemistry* 11 2627-2633

Pette D Smith M E Staudte H W & Vrbova G (1973) Effects of long-te m electrical stimulation on some contractile and metabolic characteristics of fa t rabbit musles *Pflügers Arch* 338 257-272

Plyley M J & Groom A C (1975) Geometrical distribution of capillaries in mammalian striated muscle *Amer J Physiol* 228 1376-1383

Ranvier L (187) Note sur les vaisseaux sanguins et la circulation dans les muscles rouges *C R Soc Biol (Paris)* 26 28-31

Romanul F C A (196) Enzymes in muscle I Histochemical studies of enzymes in individual muscle fibres *Arch Neurol (Chic)* 11 355-368

Romanul F C A (1965) Capillary supply and metabolism of muscle fibers *Arch eurol (Chic)* 12 497-509

Romanul F C A & Pollock M (1969) The parallelism of changes in oxidative metabolism and capillary supply of skeletal muscl fibers In *Modern Neurology* ed S Locke pp 203-13 Little Brown and Co Boston

Romeis B (1948) *Mikroskopische Technik*, p 200 Old nbourg München

Salmons & Vrbova G (1969) The influence of activity on some contractile characteristics of mammalian fast and slow muscles *J Physiol (Lond)* 201 535-549

Hermansen L & Wachlová M (1971) Capillary density of skeletal muscle in well-trained and untrained men J appl Physiol 30 860-863

Holloszy J O Oscai L B , Molé P A & Don I J (1971) Biochemical adaptations to endurance exercise in skeletal muscle In *Muscle metabolism during exercise* eds B Pernow and B Saltin pp 51-61 Plenum Press New York

Hudlicka O (1973) *Muscle blood flow Its relation to muscle metabolism and function* Swets & Zeitlinger B V Amsterdam

Hudlická O Brown M Cotter M Smith, M & Vrbova G (1977) The effect of long-term stimulation of fast muscles on their blood flow metabolism and ability to withstand fatigue *Pflügers Arch* 369 141-149

Jansson E & Kaijser L (1977) Muscle adaptation to extreme endurance training in man *Acta physiol scand* 100 315-324

Khan M A (1976) Histochemical characteristics of vertebrate striated muscle A review *Prog Histochem Cytochem* 8 1-48

Kugelberg E & Edstrom L (1968) Differential histochemical effects of muscle contractions on phosphorylase and glycogen in various types of fibres relation to fatigue *J Neurol Neurosurg Psychiat* 31 415-423

Lee J C-Y (1958) Vascular patterns in the red and white muscles of the rabbit *Anat Rec* 132 597-611

Lindhe J & Branemark P-I (1970) Observations on vascular proliferation in a granulation tissue *J Periodontal Res* 5 276-292

McKinney R V & Panner B J (1972) Regenerating capillary basement membrane in skeletal muscle wounds - Ultrastructural and histochemical study *Lab Invest* 6 100-113

Meyer J (1853) Ueber die Neubildung von Blutgefassen in plastischen Exsudaten seroser Membranen und in Hautwunden *Ann Charité-Krankenh (Berlin)* 4 41-140

Murphy R A & Beardsley A C (1974) Mechanical properties of the cat soleus muscle in situ *Amer J Physiol* 227 1008-1013

Myrhage R Eriksson E & Lisander B (1973) Intravital microscopy of the circulation in white adipose tissue *Bibl anat (Basel)* 11 399-404

Nachlas M M Tsou K -C De Souza E Cheng C-S & Seligman A M (1957) Cytochemical demonstration of succinic dehydrogenase by the use of a new p-nitrophenyl substituted ditetrazole *J Histochem Cytochem* 5 420-436

Saunders R L de C H , Lawrence J Maciver D A & Nemethy, N (1957) The anatomic basis of the peripheral circulation in man, or the concept of the macromesh and micromesh as illustrated by blood supply of muscles in man In *Peripheral circulation in health and disease* eds L Redish F F Tango and C H Saunders pp 113-145 Grune & Stratton, New York

Schmalbruch H & Kamieniecka Z (1975) Histochemical fiber typing and staining intensity in cat and rat muscles *J Histochem Cytochem* 23, 395-401

Schmidt-Nielsen, K & Pennycuik P (1961) Capillary density in mammals in relation to body size and oxygen consumption *Amer J Physiol* 200 746-750

Schoefl, G I (1963) Studies on inflammation III Growing capillaries Their structure and permeability *Virchows Arch path Anat* 337 97-141

Smith R S (1961) The development of mast cells in the vascularized cornea *Arch Ophthal* 66 383-390

Spalteholz, W (1888) Die Vertheilung der Blutgefasse im Muskel *Abhandl d K S Ges d Wiss* 24 507-534

Spalteholz W (1911) *Über das Durchsichtigmachen von menschlichen und tierischen Präparaten* Verlag von S Hirzel Leipzig

Stein J M & Padykula H A (1962) Histochemical classification of individual skeletal muscle fibers of the rat *Amer J Anat* 110, 103-123

Stingl J (1969) Arrangement of the vascular bed in the skeletal muscles of the rabbit *Folia morph (Prague)* 17 257-264

Stingl J (1973) Architektonika a ultrastruktura cévního řečiště kosterního svalstva *Plzeňský lék Sborn* 33 83-117

Stoel G (1925) Über die Blutversorgung von weissen und roten Kaninchenmuskeln *Z Zellforsch* 3 91-98

Valdivia E (1958) Total capillary bed in striated muscle of guinea pigs native to the Peruvian mountains *Amer J Physiol* 194 585-589

Zucman J (1960) Studies on the vascular connexions between periosteum bone and muscle Part one *Brit J Surg* 48 324-328

JOHANNES MEYER

Legg-Calvé-Perthes' Disease

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Legg-Calvé-Perthes' Disease

Radiological Results of Treatment
and Their Late Clinical Consequences

A Study of the Efficacy of
Three Methods of Treatment
- Wheelchair
- Bed rest without traction
- Traction in bed

BY

JOHANNES MEYER

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PREFACE

In 1955 Professor *E Thomasen* conceived the idea to try treating Legg Calve Perthes disease (LCPD) in a wheelchair

Thus idea was realized in the Orthopaedic Hospital Århus and in the late 1960s *Jorgen Lauritzen* initiated a study on the results In 1967 Professor Thomasen asked me to assist Dr Lauritzen in a way so that it would be possible to compare the radiological results of wheelchair treatment with those obtained by traction in the Seaside Hospital Refsnæs

This collaboration was the starting point of the present publication and I am therefore greatly indebted to Professor Thomasen for the invitation to collaborate in the study of the wheelchair series

My collaboration with Dr Lauritzen was very successful That to me it was an inspiration is witnessed by the volume I am submitting now For the many years of good collaboration and pleasant hours spent together I am sincerely grateful

For assistance in the follow-up examinations I am indebted to *Knud Mose* M D Physical Therapy Department Central Hospital Nykobing Falster and to Drs. *Louise Hjorth* and *Mette Ulfeldt* For help and guidance in assessing X ray films I acknowledge my indebtedness to *Marcus Schalimt ek* M D *Erik Rosigaard Christensen* M D and *Ellen Jensen* M D Radiology Department Orthopaedic Hospital, Copenhagen as well as to *Henrik Schioler* M D Radiology Department Rigshospitalet University of Copenhagen

I am indebted to *Hans Bohr* M D Head of the Seaside Hospital Refsnæs for the permission to use case records for patients treated in that hospital and for the kind helpfulness with which I am invariably met by Dr Bohr and his entire staff

For the statistical calculations my thanks are due to *Jorgen Nyboe* Head of the Statistical Department Rigshospitalet University of Copenhagen

This study could not have been performed or published without grants from Statens lægevidenskabelige *Forskningsråd* Rigsforeningen til Gigtens Bekæmpelse *Daell Fonden* and a Foundation established by former patients in the Seaside Hospital Refsnæs and others I wish to extend my thanks for this support

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CONTENTS

INTRODUCTION

In a previous study (Meyer 1966) it was endeavoured to assess the efficacy of 4 different methods of treating Legg-Calve Perthes disease (LCPD) Bed rest *with traction* bed rest *without* traction ambulatory relief from weight bearing with *Thomas splint* *no or merely symptomatic* treatment

During recent years I have also had occasion to study the efficacy of another therapeutic method – in collaboration with Jorgen Lauritzen and through the kindness of Professor E Thomasen – viz ambulatory relief from weight bearing in *wheel chair* The results of this method were compared with those of two of the previously studied methods *Bed rest with and without traction* – the methods used by me

In the course of these investigations it was realized that the methods of assessment used in the previous study were insufficient when the treatment in wheel chair was included in the evaluation

The following principal views must be maintained in assessing therapeutic results

The value of any treatment must be assessed according to the *clinical* result obtained In the evaluation the share of treatment must be elucidated as far as possible taking into consideration also the strain it has been on the patient The significance of *the radiological* result is restricted to its relation to the clinical condition

First as regards the clinical result

A year or two after the discontinuation of treatment the radiological appearances show that after the stage of fragmentation the contours of the affected femoral head are again uninterrupted and well-defined so that the deformity of the head and thus also of the hip joint after treatment may be assessed This time may be called the time of *primary healing* and is thus determined on the basis of the X ray film – one might say the radiological condition

At the time of primary healing the clinical condition is practically always good The children are broadly speaking symptom free regardless of the treatment used

On the other hand the *late* clinical condition at the end of many years is often poor characterized by increasing osteoarthritis – so-called secondary osteoarthritis – and this is the *condition on* which the assessment of the efficacy of treatment must be based

However the late *clinical condition* cannot – at present – be directly observed In the most recent follow up studies of the earliest treated materials (Helbo 1953 Gower and Johnston 1971 Danielsson & Hernborg 1965) the patients have reached a mean age of only about 40 The entire

rest s nes) they were in fact of approximately the same order of magnitude at least thus was how they were interpreted In the other series which to me were second hand it was difficult at least to *establish with* certainty the stage at institution of treatment All considered the conclusion of the 1966 study was that the named other factors did not vary so widely in the series concerned that they had to be considered Therefore when determining the primary deformity of the hip joints in the various series by the special measuring methods it was concluded that the differences reflected the efficacy of the treatments applied No doubt this was in the main correct with regard to the traction series and bed rest series – the two series of most interest – less correct in the others

However when the result of ambulatory *wheelchair* treatment was to be compared with those of the other therapeutic methods it was found that the wheelchair series differed appreciably from the other series in respect to those factors which apart *from treatment exert an essential influence* upon the primary radiological deformity of the joint The relatively simple procedure used in the study from 1966 was no longer sufficient In the assessment regard had to be paid to a much greater extent to the influence of other factors This was attained by *extending* and supplementing the 1966 method This I hope improved method was applied to the old bed rest series an increased traction series and the wheelchair series As might be expected the results found for the two previously investigated therapeutic methods were practically the same as found in 1966 only elaborated in more detail so as to permit comparison with the *results of treatment in wheelchair* This elaborated method for the radiological evaluation of the therapeutic results will be described in the next sections

The *plan* of the study to be described below was thus

1 To give a well defined quantitative description and assessment of the nature and extent of the *radiological deformities of the joints in* the three series at primary healing In other words it was endeavoured to arrive at a measure of whether and if so how much the affected hip joint differs from normal after *completion* of treatment
2 To determine the *influence of the various above mentioned factors* upon the radiological appearances especially with a view to isolating the role of treatment
3 To predict the *later clinical course* – i e assess the risk of osteoarthritis on the basis of the radiological appearances in the series at primary healing

   In other words it was endeavoured partly to determine the *relative* risk of osteoarthritis in the various series partly the *absolute* risk of osteoarthritis in the individual series The former does not pose much difficulty but the latter certainly does This may be stated more accurately Deciding which degree of radiological deformity of the joint can be accepted at primary healing if the late clinical result is to be designated good

In particular it was the achievement of the second item of the plan which required elaborating and supplementing the old methods The third item – especially its *last part* – was the most difficult one and the result least reliable True this did not necessitate new methods but a deeper probing into the problem was required to substantiate the reliability of the conclusion

In carrying through the plan all measurements were performed by *two persons* This was done to test whether the measuring *methods* were applicable by two investigators independently of *each other with consistent results* This is of the utmost importance with a view to com

subsequent development of osteoarthritis – perhaps the most important part – has not been established by direct observation

But although the subsequent development of osteoarthritis has not yet been directly observed we are not debarred from assessing the efficacy of the therapeutic methods The fact is that even at an early juncture it is possible to predict indirectly and in broad features the development of osteoarthritis In their follow up studies of fairly large series int al Sundt, Helbo and Danielsson & Hernborg arrived at the main thesis that the time of onset of secondary osteoarthritis and its severity were directly proportional to the radiological deformity of the hip joint at primary healing The greater the divergences from normal the greater the risk of osteoarthritis Of course this rule is based merely upon experience concerning the development of osteoarthritis up to the age of about 40 – but there is nothing to indicate that it could not apply also to subsequent development of osteoarthritis

Thus if we have a method for objectively determining – measuring – the radiological deformity of the hip joint at primary healing it is possible to establish with reasonable certainty already at this early juncture whether one treatment is more effective than the other in preventing the occurrence of secondary osteoarthritis This means the *relative* efficacy of the methods

This method also affords some idea of the absolute factual development of osteoarthritis in the series Those cases that have healed with practically normal femoral heads may be regarded without major errors as having no risk of osteoarthritis The percentage of the remaining cases then indicates the maximum possible extent of osteoarthritis in the series But this indirect method affords no concrete information about the actual time of onset of osteoarthritis if any its actual extent or severity Such information is obtainable only if it is possible to establish a definite relationship between early radiological deformities and the clinical nature of the late osteoarthritis This may be tried but it is inevitably uncertain – and the accuracy of the result can be ascertained only by direct late observation

The indispensable basis for any assessment of the efficacy of the various therapeutic methods, therefore, must be giving a dependable picture of the radiological deformities at primary healing in the available materials Not until then can any attempt be made to elucidate the clinical consequences of these radiological results

However the primary deformity of a hip joint is dependent not only upon the treatment Several factors seem to be operative (Mose and others)

1 Treatment
2 Age at onset of the disease
3 Stage of disease at institution of treatment
4 Sex

Moreover genetic and constitutional factors must be expected to influence the result but so far these factors are outside the scope of objective assessment In materials from a racially homogeneous population and from a geographically uniform area however the influence of such constitutional factors may presumably be expected to be of approximately the same extent in the various series

Then in assessing the relative efficacy of different treatments it is not sufficient merely to determine the radiological deformity of the hip joints after completion of the treatments We must also isolate the share of treatment in the radiological result from the influence of the other factors

This problem is eliminated if the series to be assessed vary only with regard to treatment being largely uniform as to the other factors In the 1966 study the present author determined the named factors in the different series In the series treated *with* traction and with bed rest *without* traction (called traction series and bed

A RADIOLOGICAL ASSESSMENT OF THERAPEUTIC RESULTS

1 Methods of Assessment

A radiological description of articular deformities at primary healing should preferably bear the closest possible relationship to the *risk of osteoarthritis* in the series Therefore in selecting methods of radiological description care must always be taken that the phenomena measured really do bear relationship to the risk of osteoarthritis This risk must be included in the considerations Therefore it is inevitable that even the radiological section should include a discussion of clinical problems A more detailed discussion of the clinical significance of the radiological results will follow in Section B

The development of deformity in the hip joint in the course of the disease is a somewhat complicated process Primarily the *epiphysis* gets deformed because of the disease process localized therein To the epiphyseal deformity the bony tissue in the metaphysis reacts by compensating growth processes trying to maintain the normal spherical shape of the femoral head (2/3–3/4 of a sphere as the joint surface normally makes up about 2/3–3/4 of a spherical surface) This may be accomplished in the mild epiphyseal deformities, but as a rule the head as a whole will get deformed In some cases it flattens i e the joint surfaces remain parts of a spherical surface – but only a smaller part than normal with a longer radius. In other cases the joint surface cannot be maintained as a spherical surface and it assumes a more irregular shape

These deformities of the head again induce reactions from the bony tissue in the *acetabular roof* viz compensating growth processes trying to adapt the acetabular joint surface to the deformed joint surface of the head This will widely succeed – but the deformity of the head may become too marked In other words the acetabular changes are secondary to and vary largely in proportion to the deformity of the head

A side effect to the severe cases of epiphyseal disease will be a reduction in the function of the epiphyseal line and thereby a reduction in the longitudinal growth of the femoral neck As the epiphyseal line of the trochanter which looks after the longitudinal growth of the lateral part of the proximal end of the femur is undamaged the longitudinal growth of the entire proximal femoral end will become lopsided It remains normal laterally but is inhibited medially This gradually leads to varus deformity of the neck Thus a shortening and varus deformity of the neck also bear relation to the deformity of the head Shortening and varus deformity of any extent occur only in the presence of severe

paring therapeutic results obtained in different clinics and by different clinicians

It was Professor E Thomasen who suggested this testing The measurements were performed by Jorgen Lauritzen and Johannes Meyer (LAU and J M) The results will be described in a special section supplemented by a discussion of the two investigators' somewhat divergent conclusions on the basis of the measurements (p 78)

Lauritzen *reported his results in 1975* (Diss)

Total *Survey of abbreviations and symbols*
fixed and defined in *the radiological section*

Abbreviations Wh = wheelchair BR = bed rest without traction Tr = traction in bed (often used in combinations such as Wh series Tr treatment, etc)

Symbols for patient groups (*with features of significance in the evaluation)*

A Patients arriving early for treatment i e during the stage of condensation without flattening (initial quot >85)

B Patients arriving late for treatment i e in the stage of condensation with flattening (initial quotient $\leqslant 85$) or in the stage of fragmentation

I Patients aged $\leqslant$ 4 years at institution of treatment

II Patients aged 5–8 years at institution *of treatment*

III Patients aged $\geqslant$ 9 years at institution of treatment

SPH Cases healed with spherical heads – i e heads whose surface measured with Mose s plate has a circular countour in 2 planes

NORM sph Cases healed with spherical heads of normal shape and size (*Ep qu* >60 *jt surf qu* >85 radius qu <115 – i e all quotients within the normal range *cf Appendix Comment 1*)

PATH sph Cases healed with spherical heads of pathological shape and/or size (at least one of the quotients outside the normal range)

NON sph Cases *healed with non spherical* heads (without circular contour)

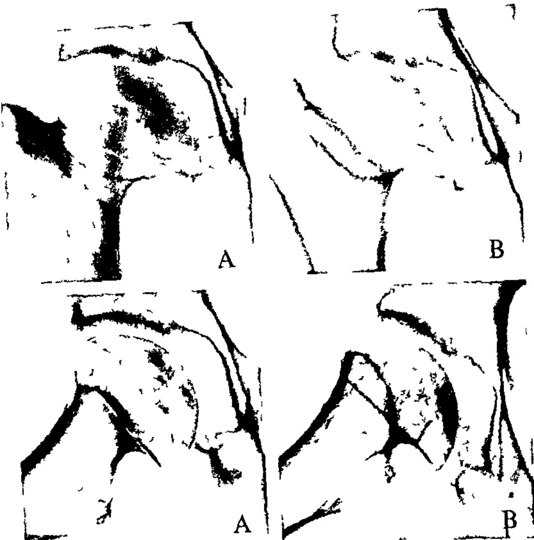


Figure 1 Two cases of right sided LCPD healed with femoral heads which though "spherical" in Mose's terminology are greatly deformed
Thus these cases belong to the group PATII sph
Anteroposterior and Lauenstein views

A ♂ aged 18 years
Ep quot 65 jt surf quot 80 ra quot 127

B ♂ aged 22 years.
Ep quot 59 jt surf quot 66 ra. quot 138

shaped heads in which the contours are circular but make up only a small part of a circle with a long radius (Fig 1)

In other words there is a wide scope of deformities within this group which therefore ought to be divided into a couple of smaller but well-defined groups It was attempted to attain this by picking out those cases in which the difference in shape and size between the affected and unaffected head *does not exceed that which may be observed between the right and left head in X rays of a normal pelvis* The remainder – the other group – will then comprise cases in which the head is spherical but the difference in shape and (or) size between the affected and unaffected head is beyond what may be observed in normal persons

The former group is of importance seeing that it may reasonably be predicted that these cases having essentially normal

deformities of the head – e g the typical, flat mushroom on a short stalk

Mild subluxation of the hip joint has often been reported as being among the sequelae to LCPD In my experience, this is very uncommon At any rate it occurs like the changes of the neck only in the presence of very pronounced deformity of the head – and acetabulum

All considered *the deformity of the hip joint is determined by the deformity of the femoral head* Accordingly there is no need to perform special measurements of acetabular deformity the position of the head in the acetabulum or of the length and position of the neck It is fully adequate to measure only the deformity of the head when looking for information about the deformity of the hip joint as a whole

As mentioned above the radiological deformity of the head extends over a wide range – from slight flattening" with preserved spherical shape of the joint surface to actually angular heads A striking phenomenon broadly speaking common to all is *a marked increase in the growth of the head* This comprises also though to a lesser extent the acetabulum Unlike the shortening of the neck and the coxa vara an increase in growth may occur also in the mildest deformities indeed it may be seen in some cases without deformity The affected head is merely larger than the unaffected one The role of this enlargement in the risk of osteoarthritis is difficult to estimate There is little doubt that the risk of osteoarthritis at a given deformity of the head will be increased when the affected head is also larger than the contralateral one the curvature of the joint surface getting smaller The effect is accentuated when the increase in acetabular growth is unable to keep pace with that of the head so that the head grows too large for the acetabulum

On the whole it may be said that a description of head deformity is incomplete without recording the attendant enlargement (Therefore the word deformity as used below will signify deformity + enlargement unless otherwise apparent from the context)

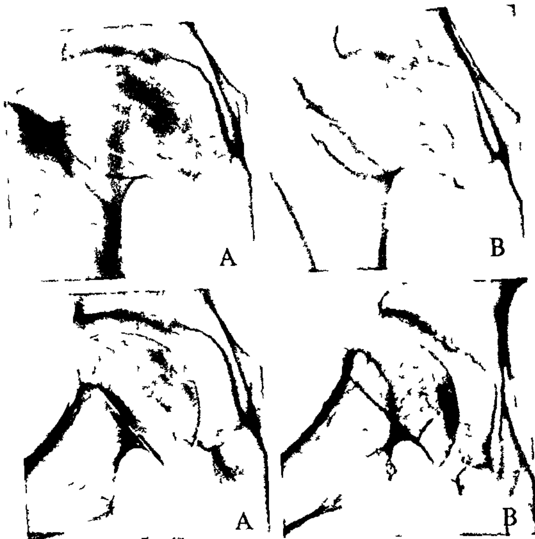
However a description of the deformity of an affected head presupposes a normal head as reference and this is available only in unilateral cases – viz the head on the unaffected side As a result, the assessment was done *only in unilateral cases* – presupposing that in bilateral cases, under the same circumstances the hip joints are affected exactly as in unilateral cases

The determination of the radiological deformity of the femoral head was carried out as follows (For a more detailed description cf Meyer 1966)

First all bilateral cases were excluded In all the series they made up 15–17 %

Thereafter the unilateral cases were divided into two groups (1) cases with *spherical heads* (2) cases with *non spherical* irregular heads The distinction was done by the aid of Mose s plastic plate with scored circles A femoral head was classified as *spherical* when one of the circles covered the contours of the joint surface in the anteroposterior as well as in Lauenstein s view (a 2 mm variation in radial length was permitted in one plane and between two planes) If this demand could not be fulfilled the head was calssified as *non spherical* irregular This applies to large flat heads whose contours are more curved along the edges than centrally as well as to the angular ones Within this group the deviation from normal is so great that the clinical prognosis must be definitely poor with a great risk of osteoarthritis

If only the series has been fairly well treated the group of spherical heads is a large one in which the capital shape ranges from entirely normal – like that of unaffected femoral heads – by way of somewhat flattened heads in which the joint surface makes up a smaller part of a sphere with a longer radius than on the unaffected side to the greatly deformed mushroom



Figu e 1 Two ses of right sided LCPD healed with femoral heads which tho gh "spherical" in Mose s terminology are greatly deformed.

Thus these cases belong to the group PATH sph

Anteroposterior and La enstein views

A ♂ aged 18 years
Ep q ot 65 jt surf quot 80 ra quot 127

B ♂ aged 22 years.
Ep quot 59 jt surf quot 66 ra quot 138

shaped heads in which the contours are circular but make up only a small part of a circle with a long radius (Fig 1)

In other words there is a wide scope of *deformities within this group which there* fore ought to be divided into a couple of smaller but well-defined groups It was attempted to attain this by picking out those cases in which the difference in shape and size between the affected and unaf fected head *does not exceed that which may be observed between the right and left head in X rays of a normal pelvis* The remainder – the other group – will then comprise cases in which the head is spher *ical but the difference in shape and (or)* size between the affected and unaffected head is beyond what may be observed in normal persons

The former group is of importance seeing that it may reasonably be predicted that these cases having essentially normal

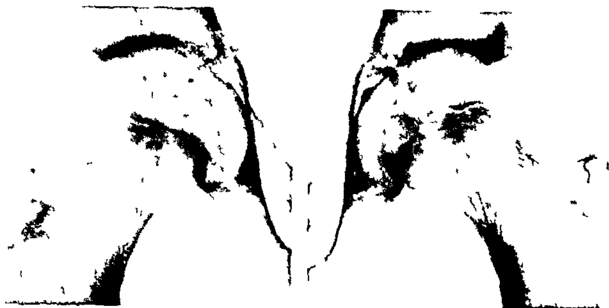


Figure 2 Left sided LCPD healed with a normally spherical *femoral head*
This case then belongs to the group NORM sph
Anteroposterior view
♂ *aged 14 years*
Ep quot 78 jt surf quot 86 ra quot 111

The joint surface quotient is just above the bottom limit of the normal range

femoral heads, must have a favourable clinical prognosis at least as compared with the other groups However, these hip joints are not *entirely* normal The affected and unaffected head are rarely exactly alike In the majority of cases there is a slight difference (but within the normal range) In *a normal* material on the other hand *the right and left head are exactly alike in* the majority of cases – deviations occurring in only a very few Perhaps this difference between the mild capital deformities in this group and the slight physiological deviations in a normal material are not devoid of prognostic significance but let us start by supposing that the risk of osteoarthritis in this group is *not appreciably greater than the risk of primary osteoarthritis in normal persons* (Fig 2)

In the group comprising the remaining patients with spherical heads we are dealing with real capital deformities and increases in growth considerably exceeding the modest normal variations In this group the clinical prognosis must be at least inferior to that in the 1st group

It may be said, briefly, that the 1st group comprises all cases with normally spherical – i e in fact normal – heads and the second group all cases with pathologically spherical heads Below the former group will be abbreviated *NORM sph* and the latter *PATH sph* The third group of patients with abnormal non spherical heads will be designated *NON sph* – and the large group with spherical heads *SPH*

Thus the presupposition for dividing the spherical cases into two groups must be accurate methods of determining the shape and size of the spherical head

Three such methods were used Measurement of the *epiphyseal quotient joint surface quotient* and *radius quotient*

Let it be emphasized at once that these methods are *applicable only to spherical heads* with well defined circular contours They cannot be applied to irregular or fragmented heads as the quantities radius of head and height of epiphysis which are included in the measurements make no

sense in such cases and are therefore not measurable

A detailed description of these methods was given previously – Meyer 1966 pp 39 42 92 and 93 so that here it will only be briefly stated what they mean

The joint surface quotient is a direct expression of the shape of the affected joint surface and thereby the affected head in relation to the unaffected head An increase in capital size does not affect the joint surface quotient In a group of normal persons the joint surface quotient is usually *100 but in a few cases it may be as* low as 85

The epiphyseal quotient is a direct expression of the shape of the affected *epiphysis i e its flattening as compared* with the unaffected one (but not as stringently stereometrically as the joint surface quotient expresses *the shape of the joint* surface) Increased growth of the epiphysis also does not affect the epiphyseal quotient In a normal material the epiphyseal quotient is usually 100 but may in a few cases be as low as 85

The applicability of the epiphyseal quotient as a *measure of capital shape* is due to a rule set up by Mose Even though the epiphysis gets deformed (flattens) beyond the range in a normal material so that the epiphyseal quotient drops below 85 the above mentioned compensatory growth processes in the metaphysis (possibly as far down as the neck) will *maintain the normal shape of the head* so that it is not deformed beyond the normal range By *careful but not quantitative observations* the correctness of which I can confirm Mose ascertained that such maintenance of normal capital *shape occurred if only the* epiphyseal quotient *exceeded 60* Thus the epiphyseal quotient could be used as a *measure of capital shape* When the *epiphyseal* quotient exceeded 60 the shape of the head was within the normal range If an epiphyseal quotient of 60 is not used in the radiological assessment as the bottom limit of normally shaped heads in *LCPD* series but an epiphyseal quotient of 85 – which is the bottom *limit of epiphyseal* quotients in normal children – it is not possible to single out *all* cases with normally shaped *heads* in the LCPD series only those *with normally shaped epiphyses.* Accordingly, this quantity is of no prognostic importance, but is a good measure of whether the treatment is able to prevent epiphyseal *flattening.*

In other words the epiphyseal quotient may be used to single out cases with normally shaped heads in a LCPD series

Below normal range of the epiphyseal quotient refers simply to the range in *normally shaped heads* – comprising in a series of LCPD all *epiphyseal quotients* >60 *i or the range in normal children* in whom the epiphyseal quotients never go below 85 (cf Appendix Comment I)

Now we *have two measures of* capital shape after LCPD The *joint surface quotient* which directly measures the shape of the femoral head and the *epiphyseal quotient* which directly measures epiphyseal shape but indirectly may be applied – by using Mose s rule – as a measure of capital shape

Both measurements have their advantages and disadvantages One might think that the direct *measurement* of capital shape the joint surface quotient would be preferable but matters are not so simple Measurement of the joint surface quotient *is rather more complicated* than measurement of the epiphyseal quotient – and therefore also carries somewhat greater *uncertainty* On the other hand Mose s rule – epiphyseal quotient exceeding 60 = normally shaped head – is not based upon objective measurement but upon an estimate although it *seems reliable it is* nevertheless a subjective estimate However measurement of the epiphyseal quotient *has the advantage* of being the method most often used by previous authors – but rarely applying Mose s rule and this *renders the* assessment of their results somewhat more difficult

In fact, it is difficult to decide which measuring method is more reliable As a rule their results agree, as may be expected Only, there seems to be a tendency for the difference between the results in two series to be greater measured by the epiphyseal quotient than by the joint surface quotient (The cause is not quite evident but the phenomenon is possibly related to the application of an epiphyseal quotient >60 as a normal value not compensating entirely for the epiphyseal shape varying more than capital shape)

However the difference between the results of the two methods is slight – but there *are* differences, due to various inaccuracies attaching to the two methods

Considering the great importance of measuring the shape of the affected head with a view to the risk of osteoarthritis, I preferred whenever possible to use *both* measurements hoping that they could act as mutual control and thereby perhaps disclose measuring errors and accidental divergences At least good agreement between the two measuring methods in dividing the group with spherical heads will increase confidence in the correctness of the results

The third measurement that of the *radius quotient* is the simplest one The radius of the affected head divided by that of the unaffected head In a normal material the radius quotient is usually 100 but may sometimes rise to 115

The main advantage of the radius quotient is that it is influenced by the size of the femoral head – which does not apply to the other two quotients In return it is not *directly* influenced by the shape of the head The head *may* easily change in shape i e alter from a large part of a sphere – as in normal children – to a smaller one without its radius and thereby its radius quotient undergoing the slightest alteration

It is a different matter altogether that a major change in the shape of the head is usually accompanied by a greater reactive

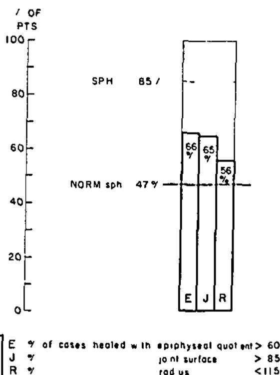


Diagram 1 Example of dividing the SPH group into two sub groups by means of one figure % NORM sph instead of into 3 x 2 groups by means of 3 figures one % for each of the 3 quotients

The patients of the material are imagined to be listed by increasing joint deformity from below and upwards

SPH = Cases healed with spherical heads

NORM sph = Cases healed with spherical heads in which all 3 quotients are within the normal range (Ep quot >60 Jt surf quot >85 Ra quot <115)

(Abbreviations and symbols cf survey p 12)

skeletal growth in and around the joint – a greater increase in growth – than a minor change in shape

Therefore a major change in shape is generally associated with a longer radius *Indirectly* then the radius quotient is influenced by a change in shape

In practice assessment by radius quotient is a little stricter than assessment by the other measuring methods - presumably because the radius quotient is affected by any increase in growth also an increase in growth without any change in shape

However measurement of the radius quotient has a drawback which has to be taken into account *It has been a presupposition* of the considerations above that the

final shape and size of the head could be determined at the time of primary healing a year or two after completion of treatment Indeed this is right in all essentials – but not quite During the period between primary healing and completion of growth there occurs some reduction in the difference between the affected and unaffected head with regard to shape as well as size mostly the latter The unaffected head grows relatively more than the affected one during continued growth until puberty Consequently the measurements will improve especially the radius quotient This improvement is most marked up to the age of 9 years – and thereafter slight

Ideally then all measurements should not be carried out until after the completion of growth at the age of 16 possibly after the age of 9 as thereafter the changes are negligible However this is difficult to practice in the case of all patients Therefore the demand must be confined to aiming at a fairly equal age distribution in the series to be compared i e approximately equally long follow-up periods somewhat longer in series with the earliest onset of the disease and the largest possible number of patients over 9 years of age at the time of the measurements

From what has been stated above it is apparent that in an attempt at grouping the patients with spherical heads into the two groups NORM sph and PATH sph by *each* of the three radiological measuring methods the size of the groups *will not* be the same

Measurement of the epiphyseal quotient and of the joint surface quotient affords approximately but not quite the same result whereas measurement of the radius quotient gives a somewhat smaller group of NORM sph than the other two

But the object was to *perform one well defined grouping* that could be expressed by 1 figure – not 3 groupings expressed by 3 figures one for each measuring method

This is practicable only if it is demanded that the group NORM sph *should comprise* only patients in whom *all three measuring methods afford results within the normal range* (epiphyseal quotient >60 joint surface quotient >85 and radius quotient <115) while the remainder – i e all cases in which merely one method gives a result beyond the normal range – are assigned to the group PATH sph

This affords not only a division into two groups whose size may be expressed in 1 figure but it also makes the group NORM sph correspond better to the definition Cases healed with heads of normal shape and size (Fig 2) The criterion of belonging to the group NORM sph is thereby stricter than when based merely upon the result of one measuring method – and the size of the group consequently smaller (Diagram 1)

The distinction of such a group based upon the result of *three* measuring methods was suggested by Jorgen Lauritzen (thesis 1975) and will be used below in dividing the group SPH

(As to the possibility of grouping by the aid of merely one of the measuring methods cf Appendix Comment 3)

Let us now briefly recapitulate the *terminology* concerning the various groups of patients to be used below in the text tables and diagrams (Diagram 2)

The large group of patients with spherical heads will be called SPH It will be divided into two sub-groups called NORM sph and PATH sph The third group with abnormal *irregular heads* will be called NON-sph

This division of the series into 3 groups forms the basis of the following descriptions but a simple division into two groups may also be desirable The series might be divided for instance into cases with normal heads and cases with abnormal heads In that case the groups will be designated simply NORM and PATH – the former referring to the same group as

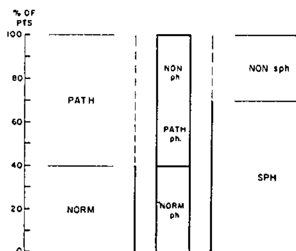


Diagram 2 Terminology in dividing an LCPD series at primary healing on the basis of the radiological shape and size of the affected femoral head

NORM = Cases healed with heads of normal shape and size (= NORM sph vide infra)

PATH = Cases healed with heads of pathological shape and/or size

SPH = Cases healed with spherical heads

NON sph = Cases healed with non spherical heads

NORM sph = Cases healed with spherical heads in which the 3 quotients Epiphyseal quotient joint surface quotient and radius quotient are within the normal range (Ep quot >60 Jt surf quot >85 Ra quot <115)

PATH sph = Cases healed with spherical heads in which one or more of the 3 quotients are outside the normal range

On the diagram the patients of the material are imagined to be listed by increasing joint deformity from bottom to top

The grouping of the material was arbitrarily selected (Abbreviations and symbols cf the survey p 12)

NORM sph and the latter combining the groups PATH sph and NON sph A division into two groups according to whether or not the heads are spherical may also be considered In that case the former group will be identical with SPH the latter with NON sph These divisions into two groups are simpler but whether they are too simple cannot be decided until later

In assessing his series, Mose used a division into 3 groups according to exactly the same principles Only, in dividing the group with spherical heads he employed just *one* measuring method *Epiphyseal quotient* The three groups of patients which resulted from this division of his series were called ' good , fair ', and "poor" Although the following assessment is based upon *three* measuring methods, the terms good, fair, and poor might easily have been transferred to the three groups into which the series were divided also at the present assessment However these terms seemed less apt, because *a priori* they included a subjective evaluation The more objective, descriptive terms NORM sph ", ' PATH sph " and NON sph " were, therefore, preferred

Should it be necessary to refer to the previous 'good and fair groups, the new terms will be used below, merely adding a letter to designate the measuring method used e g NORM sph " (J) or ' PATH sph " (E)

If it seems expedient to base the grouping upon two measuring methods – omitting e g the result of the radius quo tient measurement – this is of course also practicable if only the resulting groups are appended by two letters (J E)

Diagram 2 gives a survey of the terminol ogy used in the present paper

A list of abbreviations is given on p 12

2 Results in the Series as Referred

As already mentioned the results obtained in the series as they were referred depend not only upon the treatment but also upon sex and upon the patients age and the stage of the disease at institution of treat ment

The results to be reported in this section are due to an interaction of all these factors As the series very probably differ not only in the treatment received but also in the other factors the results tell us

nothing about the effect of these treatments under uniform conditions

In the next section it will be endeavoured to elucidate this – our main problem

In assessing all therapeutic results below most emphasis will be laid upon the number of patients with normally spherical femoral heads – the percentage size of the normal group designated *NORM sph*

This percentage is considered as a measure of the number of good results obtained by the treatment

It is only in this group that the shape and size of the head is within the normal range and therefore the risk of osteoarthritis cannot essentially exceed that of primary osteoarthritis in normal persons This must be called a satisfactory result and if this is set up as a reasonable – and well-defined – criterion of the desired result only the cases of the group NORM sph can be classified as good radiological results

In patients of the group PATH sph on the other hand the shape and size of the head are definitely abnormal and the risk of osteoarthritis accordingly greater than in people with previously healthy hip Thus if it is maintained that the risk of osteoarthritis in normals is the criterion of a good result such a result is not obtained by the patients of the group PATH sph These patients are bound to develop osteoarthritis of a somewhat greater frequency and severity than would a corresponding group of normal persons

However it is possible – and it has been claimed – that in actual fact these cases of osteoarthritis are so few and so mild that in practice it would be justified to call them good clinical results If so all cases of the large radiological group SPH could be called radiologically satisfactory

If this were right it would mean that articular deformities far beyond the normal range would have to be accepted as good radiological results

A priori this does not seem likely – Fig 1 – and is at least pending further analysis quite uncertain

As a preliminary point of view therefore only cases of the group *NORM sph* can be considered satisfactory radiological results

An essential part of the later clinical sections then will be devoted to proving – or disproving – the correctness of this viewpoint i e to investigating whether and if so to what extent osteoarthritis develops in the pathologically deformed part of the group SPH – i e in *PATH sph*

Therefore in the following radiological sections the main emphasis will be on establishing (and depicting) the size of the group NORM sph Owing to the uncertainty concerning the development of osteoarthritis in PATH sph however the size of the entire SPH group – and thus also of *PATH sph* – will be recorded

The radiological assessment concerned three series treated by three different methods

1 *113 patients* viz all patients treated for unilateral LCPD in the Seaside Hospital Refsnæs during the period 1958–1963 The majority (about 3/4) were treated by bed rest plus traction for one year followed by bed rest without traction for 6 months + ambulatory non weight bearing for another 6 months (for further details of the treatment cf Meyer 1966 p 54) One quarter of the patients who were not or only briefly treated by traction had bed rest without traction This is the traction series described by Meyer (1966) supplemented by 42 patients Below it will be designated the *traction series*

2 *114 patients* viz *all* patients started on *treatment for unilateral LCPD* in the Orthopaedic Hospital Århus during the period 1957–1964 All had ambulatory treatment in a wheelchair For details of

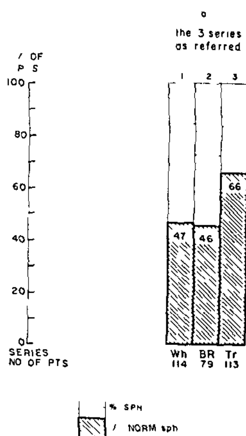


Diagram 3 Radiological results of treating

a { *1 the Wh series as referred by Wh (SPH 85 %)*
2 the BR series as referred by BR (73 %)
3 the Tr series as referred by Tr (84 %)

(1 2 and 3 signify Wh BR and Tr treatment)

A total tabulation of the radiological results is given in the Appendix Table 27

Statistical calculation

There is a significant difference in the frequency of patients with normal spherical heads (NORM sph) between

the Tr series and Wh series as referred ($p < 0.01$) and
the Tr series and BR series as referred ($p < 0.01$)
(cf also Appendix Table 28)

(Abbreviations and symbols on p 12)

this treatment cf Lauritzen (1975) This series will be referred to below as the *wheelchair series*

3 *79 patients* viz *all* those treated for unilateral LCPD in the Seaside Hospital Refsnæs during the period 1953–1957 Treatment Bed rest without traction in hospital for 18 months followed by ambulatory non weight bearing for 6 months This series has previously been published by Mose (1964) and Meyer (1966) Below it will be designated the *bed rest series*

The following abbreviations will be used, to save space on diagrams and tables

Wh = wheelchair
BR = bed rest without traction
Tr = bed rest with traction

These abbreviations will be used either alone or in combinations e g Wh series Tr treatment etc

According to the lines described above, each of these series will be divided into three groups of patients ' NORM sph PATH sph and NON sph

The results are apparent from Diagram 3 and Table 1 (details in the patient lists) and from the Appendix Tables 22 23 24

Table 1 Radiological results of wheelchair (Wh) bed rest (BR) and traction (Tr) treatment in the three series (as referred) (No of pts cf Appendix Table 26)

Radiological groups	Wh series 114 pts	BR series 79 pts	Tr series 113 pts
	%	%	%
NON sph	15	27	16
PATH sph	38	27	18
NORM sph	47	46	66

The follow up periods and patient age at the time of measurement are shown in Table 2

There might have been better agreement – but it seems acceptable In practice it is difficult to attain complete agreement It proved necessary to carry out new measurements on the traction series three years after the first ones as at that time the follow up period had been far too short and patient age too young The results of this new measurement were in striking conformity with those of the former except for the expected moderate improvements due to the longer follow up period

Table 2. Follow-up period and patient age at the time of measurement in the Wh BR and Tr series.

	Follow-up period after institution of treatment (mean)	% of pts. ≥9 years at time of measurement
Wh series (114 pts.)	5 ½ years	81 %
BR series (79 pts.)	4 ½ years	87 %
Tr series (113 pts.)	6 years	92 %

These improvements were of modest but not inconsiderable extent Thus the percentage of NORM sph had increased from 61 % to 66 %

From Diagram 3 it is evident that the percentage size of the NORM sph group i e the percentage of good results in the wheelchair and bed rest series was practically the same viz 47 % and 46 % but appreciably higher in the traction series 66 %

Considering the fairly uniform follow-up periods and ages at measurements these three values ought to be comparable as an expression of the efficacy of the three methods of treatment i e only in the series as referred without paying regard to possible differences in sex and in age as well as stage of disease at institution of treatment

From Diagram 3 (and Table 1) it is apparent incidentally that the *group SPH* (NORM sph + PATH sph) *made up* 85 % 73 % and 84 % of the wheelchair bed rest and traction series respectively

Thus the percentage of SPH was the same in the wheelchair and traction series despite the fact that the percentage of NORM sph was considerably lower in the wheelchair than in the traction series

This was unexpected in so far as in 1966 Meyer measuring the epiphyseal quotient in four series found the percentage of SPH to vary in all series by the percentage of NORM sph (E) (Meyer 1966 Diagram 20) – only with smaller differences This applied also to the joint surface quotient and radius quotient – and there is no reason why it should not apply also to NORM sph calculated on the basis of all three measuring methods In deed Diagram 3 shows that it applies to the bed rest series and the traction series Only the values for the Wh series were not according to the rule

It is difficult to elucidate the cause The values were found in the series as referred – and as they were not of the same prognostic severity the values are not directly comparable The apparent disagreement is probably due chiefly to the different nature of the series However the mechanism of action of the treatments may be operative All considered it does not seem reasonable to ponder too much at this site upon the cause of the peculiarity *in the wheelchair results This is better* deferred until the next sections which deal with the therapeutic results in comparable groups of patients

The main results of the analysis in the present section then may be briefly summed up as follows

By *the three methods of treatment* in *the series as referred about half the patients* of the *wheelchair series* and of the *bed rest series* obtained what is called at least preliminarily a good radiological result as they belong to the group NORM sph In the *traction series* this result was found in about two-thirds of the patients

Contrary to expectation the more comprehensive group SPH *proved to be of* the same size in the wheelchair and traction series despite the pronounced difference in NORM sph However the groups are of the same size only quantitatively while qualitatively the *group* SPH in the wheelchair series is appreciably inferior to that in the traction series It includes a far smaller number of cases that can be classified as NORM sph

In the *bed rest series the size* of the SPH group is as might be expected

smaller than in the traction series – corresponding to the smaller group NORM sph in the bed rest series

3 Results in Series Differing Only – As Far As Possible – in Therapeutic Methods

The results described in the preceding section express only the efficacy of the treatment in the series as referred – with the differences that may exist with regard to sex, age, and stage of the disease at institution of treatment

Thus the results are determined not only by the various methods of treatment but also by the three factors mentioned above

However, *the main problem of the* present study was the relative efficacy of the treatments under *uniform* conditions i e in series varying only with regard to the treatment not the other factors

Further elucidation of this problem will be attempted below

First the variation of the three factors in the series must be mapped – if they vary at all

Patients age at institution of treatment was as shown in Table 3

Table 3 Age distribution in the Wh BR and Tr series Percentage of patients in the series (for No of pts cf Appendix Table 26)

Series treated by	Age groups I ≤4 years	II 5–8 years	III ≥9 years
	%	%	%
Wheelchair (114 pts)	32 5	60 5	7
Bed rest without traction (79 pts)	21	61	18
Traction in bed (113 pts)	27	55	18

It is apparent that in the wheelchair series the percentage of patients in the youngest group is higher and that of patients in the oldest group lower than in the other two series The bed rest series is from the prognostic point of view the 'heaviest' one, having a lower percentage of patients in the youngest group than the traction series while in the oldest groups these series showed the same percentage ($2\frac{1}{2}$ times that of the wheelchair series (18 %/7 %)

Somewhat more uncertainty attaches to classification of the series by *stage* of disease at institution of treatment

A classification into three groups was made, by condition of the epiphysis at institution of treatment

A Epiphysis condensed – but without flattening or fragmentation
B *Epiphysis condensed and flattened but* without fragmentation
C Epiphysis distinctly fragmented

Whether a condensed epiphysis – the first two groups – was *flattened* even before institution of treatment was determined by measurement

This measurement was carried out exactly like that of the epiphyseal quotient *after completion of the treatment By* measuring epiphyseal height and width These two measurements afford a numerical expression of epiphyseal flattening

To avoid confusion with the epiphyseal quotient measured *after* completion of the treatment this new quotient measured at institution of treatment was called at the suggestion of J Lauritzen the *INITIAL QUOTIENT* Measurements of the epiphyseal quotient in normal persons have shown that without any signs of disease in the epiphysis this quotient may range from 100 down to 85 Therefore the epiphysis was deemed not flattened at institution of treatment when the similarly measured initial quotient exceeded 85 whereas an initial quotient below 85 indicated flattening of the affected epiphysis

As group C I classified cases in which the epiphysis was so fragmented as not to permit measurement of the initial quotient

In practice however it was soon apparent that group C cases were so few and so difficult to distinguish definitely from group B cases that it seemed reasonable to combine these groups into a larger group B Below then we shall operate with two groups An *early group A* and a *late group B* These groups are distinguished by measurement of the flattening of the condensed epiphysis – a measurement which is adequately well-defined and therefore affords reasonably definite distinction Group A is of a far more uniform composition than group B which contains cases in which the epiphysis was merely condensed but flattened as well as cases with severely fragmented epiphyses

Table 4 Distribution by early and late treatment in the three series. Percentage of patients in the series. (For No of pts cf Appendix Table 26)

A Cases in the stage of condensation without flattening (initial quot >85) at institution of treatment

B The remainder – i e cases in the stage of condensation with flattening (initial quot ≤85) and cases in the stage of fragmentation at institution of treatment

Cases of Dysplasia epiphysialis capitis femoris without flattening (J.M 1964) are assigned to group A

Series treated by	Stage at institution of treatment	
	Early treatment *A*	Late treatment *B*
	%	%
Wheelchair (114 pts)	65	35
Bed rest without traction (79 pts.)	49	51
Traction in bed (113 pts)	55	45

Table 4 gives the distribution into groups A and B of the three series

It will be seen that in the wheelchair series a larger number of patients had early treatment than in the other two series The largest number of cases having late treatment was found in the bed rest series

The sex ratio may be seen from Table 5

The largest number of girls were in the bed rest series the smallest in the traction series while the wheelchair series was in

Table 5 Sex ratio in the Wh BR and Tr series. Percentage of patients in the series (No of pts cf Appendix Table 6)

Series treated by	Sex	
	♂	♀
	%	%
Wheelchair (114 pts)	82	18
Bed rest without traction (79 pts.)	76	24
Traction in bed (113 pts)	86	14

between The differences are not inconsiderable but are no doubt due to chance However they seem too marked to be left out of account

If after having mapped the variation of the three factors in the series we can pick out three groups of patients one from each series in which all three factors are identical and only the methods of treatment have varied the results in these groups are determined solely by the efficacy of the treatment Thereby it would be possible to gain a clear impression of the relative efficacy of the three methods of treatment in these groups – ridded of the influence of other factors

Let us first try to obtain three groups of patients in which two factors – *age* and *stage* of disease at institution of treatment – were as uniform as possible

This may be achieved by combining Tables 3 and 4 in the way that each of the series is divided into six groups

$$A_I - A_{II} - A_{III} - B_I - B_{II} - B_{III}$$

The first group A_I – patients under 5 years of age who had early treatment – is then the "lightest" one i e the one in which the best results may be *expected* The last group B_{III} *comprises the oldest* children who had late treatment and therefore the results must be expected to be *poorest* The prognostic severity of the intermediate groups will – broadly speaking – increase from left to right

Since however *age* has most influence upon the results the results in group A_{III}

Table 6 Composition of the series with regard to patients age and stage of disease at institution of treatment (No of pts cf Appendix Table 26)
Meaning of I II III and A B cf Tables 3 and 4
% = % of all pts in the series

Series treated by	Age/stage groups					
	A I	A II	A III	B I	B II	B III
	%	%	%	%	%	%
Wheelchair (114 pts.)	21	40	4	11	20	4
Bed rest without traction (79 pts.)	6	30	12	16	30	6
Traction in bed (113 pts)	12	29	14	15	26	4

are often inferior to those in groups B_I and B_{II} If the sequence is to correspond to the increasing severity, group A_{III} ought to be moved between groups B_{II} and B_{III} This will be done when such a sequence is desired

The result of the classification is presented in Table 6

It shows that the 'lighter nature of the *wheelchair series* is even more apparent in this combination of Tables 3 and 4

A look at the number of patients in each group shows that it is regrettably small Group A_{II} is the largest one and the only single group which is perhaps sufficiently large to permit an attempt at determining the relative efficacy of the treatments in the three series In another way too A_{II} must be presumed to be suited In the very mild cases the nature of treatment is presumably of less importance to the results Practically all will be good no matter what the treatment About the same applies to the most severe cases All results are more or less poor regardless of the treatment Group A_{II} belongs to the intermediate groups in which the efficacy of the treatments will probably manifest itself more clearly

However the *sex ratio* in the groups is not the same

The percentage of girls in the A_{II} groups of the Wh BR and Tr series is 13 % 21 % and 18 % respectively The difference between these percentages is not inconsiderable (but no doubt due entirely to chance) Since, however the difference in therapeutic results in girls and boys is slight the difference in the sex ratio within the three series is not likely in spite of all to have any major influence upon the results But it is necessary first to make sure that this *assumption* is correct

The only way in which we can avoid an effect of a difference in sex ratio is by performing all analyses *only on the boys* who make up about 4/5 of all the series Therefore such analyses will be carried out to check whether the result of analysing the groups with both sexes have afforded sufficiently reliable information about the

Table 7 Results of treatment in age/stage groups in the Tr Wh and BR series as referred (No of pts cf Table 4 Appendix Table 26)
% = % NORM sph in the groups

Series treated by	Age/stage groups					
	A I	A II	A III	B I	B II	B III
	%	%	%	%	%	%
Wheelchair (114 pts)	79	48	0	46	30	0
Bed rest without traction (79 pts.)	80	54	30	58	29	(50)
Traction in bed (113 pts)	100	85	27	76	52	20

relative efficacy of the three therapeutic methods – or whether a correction for the slight sex difference is needed

In other words the main study will be on the undivided groups and series comprising both sexes Analysis of the boys alone was only done as a supplement

The results obtained in the 6 groups into which the three mixed series were divided may be seen from Table 7 – or perhaps more clearly from Diagram 4 (only for the Wh og Tr series)

From the table as well as the diagram it is apparent that largely the results get poorer the older the patients are and the later they arrive for treatment This applies also when analysing separately the rela

RADIOLOGICAL RESULTS
IN THE Wh AND Tr SERIES

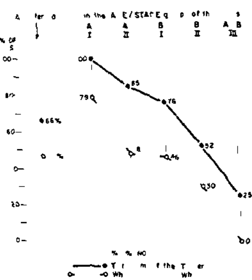


Diagram 4 Radiological results in the Wh and Tr series as referred and in the age/stage groups of these series

As the results in the oldest age group (III) are poor regardless of stage the groups A III and B III (which are very small) were combined into one (A III + B III) This affords a larger number of patients as well as a sequence of the groups from left to right according to decreasing results.

(Abbreviations and symbols as listed p 12.
% given in number of pts in the Appendix Table 26)

RADIOLOGICAL RESULTS
IN THE Wh AND Tr SERIES

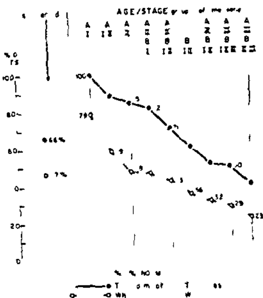


Diagram 5 Radiological results in the Wh and Tr series as referred as well as in age/stage groups of these series of increasing severity from left to right

The age/stage groups in this diagram are combined groups having a larger number of patients and a more even transition from the mildest to the most severe group than the 6 simple groups on Diagram 4 However the combined groups in both series are less comparable than the 6 simple ones.

(Abbreviations and symbols as listed p 12
% given in number of pts. in the Appendix Table 26)

tionship of the course to age and stage There are few exceptions to this rule It is evident also that the difference between the results of the three treatments – especially between Tr and the other two – is most marked in the intermediate groups (A_{II} and B_I) less in the milder and very severe cases This is even more distinct in Diagram 5 in which the 6 groups are combined in various ways into 9 so that the transition from the mildest to the most severe group is more even and the number of patients in each group larger However these combined groups are appreciably less uniform and comparable than the 6 main groups

Out of these six groups A_{II} is best suited to our purpose To determine the results of

RADIOLOGICAL RESULTS OF TREATING

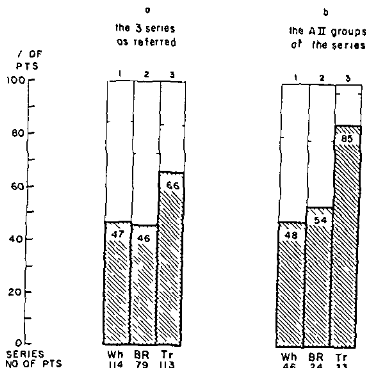
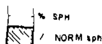


Diagram 6 Radiological results of treating

a	1 the Wh series as referred by Wh	(SPH	85)
	2 the BR series as referred by BR	(	73)
	3 the Tr series as referred by Tr	(	84 %)
b	1 the A II group of the Wh series by Wh	(SPH	80 %)
	2 the A II group of the BR series by BR	(	79 %)
	3 the A II group of the Tr series by Tr	(	97 %)



A total tabulation of the radiological results is given in the Appendix Table 27 (Abbreviations and symbols p 12)

Statistical calculation *(cf also Appendix Table 28)*
Re results in the series as referred cf Diagram 3
Re results in the A II groups of the series
There is a significant difference in the frequency of pts with normally spherical heads (NORM sph) between
the A II groups of the Tr series and Wh series ($p < 0.01$) and
the A II groups of the Tr series and BR series ($p < 0.05$)

the three methods of treatment in uniform groups of patients

The result of such an analysis is presented in Diagrams 6–7

From Diagram 6 it may be seen that the differences between the results of the three treatments are more pronounced in the A_{II} groups (uniform with regard to age and stage) than in the total series of a more heterogeneous composition

By *wheelchair* and *traction* treatment 47 % and 66 % good results i e NORM sph were obtained in the total series – in the more uniform A_{II} groups 48 % and 85 % respectively By *wheelchair* and *bed rest* 47 % and 46 % NORM sph were obtained in the total series in the A_{II} groups 48 % and 54 % respectively

These appreciably increased differences in the A_{II} groups are explicable as follows

(perhaps best illustrated in Diagram 7)

The results in the *traction* and *bed rest* series improve on transition from total series to groups A_{II} because removal of the heavy part of these severe series (groups A_{III} and $B_{I-II-III}$) has more effect than removal of the small mild A_I groups In the *wheelchair series* on the other hand the removal of the heavy end of the series counterbalances the removal of the numeri cally larger mild group A_I in the way that the result in group A_{II} of the wheelchair series is largely identical with that in the total series

Thus the more marked differences in therapeutic results between the more uni form A_{II} groups ought to afford a more reliable picture of the relative efficacy of the therapeutic methods than do the less marked differences in the total series as referred which are not uniform with regard to severity (Statistical calculation cf legend to Diagrams 3 and 6)

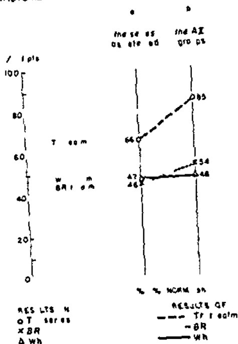


Diagram 7 Radiological results of treating the Wh BR and Tr series as referred (a) and their A II groups (b)

Diagram 6 in a more perspicuous form (only "NORM sph.)

The 3 small symbols on the vertical lines signify the results in the 3 series as referred and in their A II groups.

The oblique lines between the vertical lines connect the results of the same form of treatment

(No of pts. and % of SPH cf Diagram 6 and the Appendix Table 27 Abbreviations and symbols on p 12)

However the A_{II} grups have two essen tial defects In the first place they are too *small* comprising only 46 24 and 33 patients respectively *Therefore chance* may influence the results However it must be mentioned that the shape of the curves in Diagram 4 without any inexplicable kinks does not indicate that they are *characterized* by chance In the second place the *sex ratio* is not the same as already mentioned there being rather *more* girls in the A_{II} *group of the traction* and bed rest series than in the wheelchair series

But both defects can be remedied

The uncertainty attaching to the small number of patients in the A_{II} *groups* may be reduced if we do not restrict the analyses to utilizing only the results in the A_{II} groups but include the results *in all* groups Basing the analysis on a larger number of patients and patient groups ought to increase the statistical reliability

This may be practised as follows

Among the 114 patients of the wheel chair series 47 % good results (% NORM sph) were obtained – by wheelchair treatment The material was then divided into six groups so that the patients within each group were uniform with respect to age/stage at institution of treatment The 113 patients of the traction series were divided into corresponding groups each comprising cases of as far as possible *exactly* the same severity at admission as the corresponding groups of the wheelchair *series* Thus *one* treatment ought to afford the same result in two corresponding groups In other words *If* e g group A_{II} of *the wheelchair* series *had been treated by traction* it would have shown the same *result* as the A_{II} group of the traction series

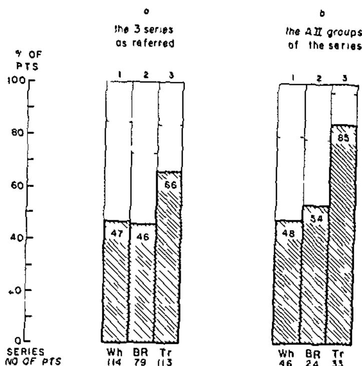


Diagram 6 Radiological results of treating

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b	*1 the A II group of the Wh series by Wh*	*(SPH*	*60 %)*
	2 the A II group of the BR series by BR	*(*	*79 %)*
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% SPH
% NORM sph

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Thus the more marked differences in therapeutic results between the more uniform A_{II} groups ought to afford a more reliable picture of the relative efficacy of the therapeutic methods than do the less marked differences in the total series as referred which are not uniform with regard to severity (Statistical calculation cf legend to Diagrams 3 and 6)

However the A_{II} grups have two essential defects In the first place they are too *small* comprising only 46 24 and 33 patients respectively Therefore chance may influence the results However it must be mentioned that the shape of the curves in Diagram 4 without any inexplicable kinks does not indicate that they are characterized by chance In the second place the *sex ratio* is not the same as already mentioned there being rather more girls in the A_{II} group of the traction and bed rest series than in the wheelchair series

But both defects can be remedied

The uncertainty attaching to the small number of patients in the A_{II} groups may be reduced if we do not restrict the analyses to utilizing only the results in the A_{II} groups but include the results in *all* groups Basing the analysis on a larger number of patients and patient groups ought to increase the statistical reliability

This may be practised as follows

Among the 114 patients of the wheelchair series 47 % good results (% NORM

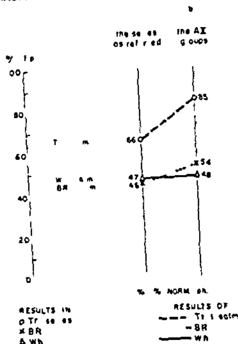


Diagram 7 Radiological results of treating the Wh BR and Tr series as referred (a) and their A II groups (b)

Diagram 6 in a more perspicuous form (only NORM sph.)

The 3 small symbols on the vertical lines signify the results in the 3 series as referred and in their A II groups.

The oblique lines between the vertical lines connect the results of the same form of treatment

(No of pts. and % of SPH" cf Diagram 6 and the Appendix Table 27 Abbreviations and symbols on p 12)

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RADIOLOGICAL RESULTS OF TREATING

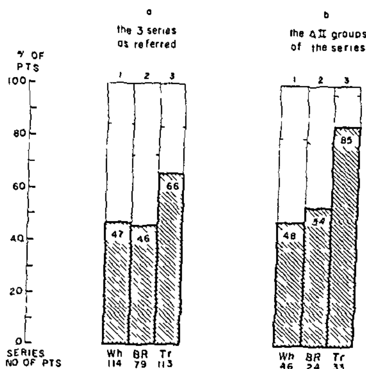
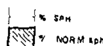


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RADIOLOGICAL RESULTS OF TREATING

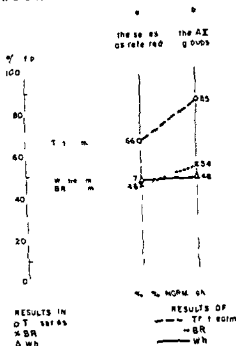


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Diagram 6 in a more perspicuous form (only NORM sph)

The 3 small symbols on the vertical lines signify the results in the 3 series as referred and in their A II groups.

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(No of pts and % of SPH " cf Diagram 6 and the Appendix Table 27 Abbreviations and symbols on p 12)

sph) were obtained – by wheelchair treatment The material was then divided into six groups so that the patients within each group were uniform with respect to age/stage at institution of treatment The 113 patients of the traction series were divided into corresponding groups each comprising cases of as far as possible *exactly* the same severity at admission as the corresponding groups of the wheelchair series Thus *one* treatment ought to afford the same result in two corresponding groups In other words *If* e g group A_{II} of *the* wheelchair series *had been treated by traction* it would have shown the same result as the A_{II} group of the traction series

RADIOLOGICAL RESULTS OF TREATING

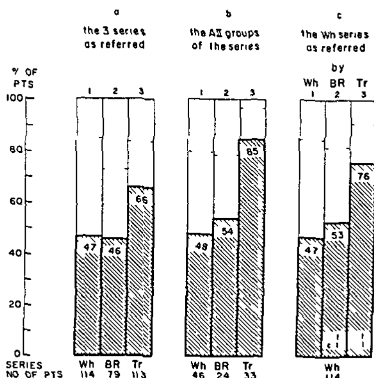


Diagram 8 Radiological results of treating

a
1 the Wh series as referred by Wh (SPH 85 %)
2 the BR series as referred by BR (73 %)
3 the Tr series as referred by Tr (84 %)

b
1 the A II group of the Wh series by Wh (SPH 80 %)
2 the A II group of the BR series by BR (79 %)
3 the A II group of the Tr series by Tr (97 %)

c
1 the Wh series as referred by Wh (SPH 85 %)
2 the Wh series as referred by BR (calculated) (82 %)
3 the Wh series as referred by Tr (calculated) (91 %)

% SPH
% NORM sph

(A total tabulation of the radiological results in the Appendix Table 27 Abbreviations and symbols p 12)

In c the Wh series as referred could be replaced with 3 identical series composed like the Wh series (with regard to patients age and stage of disease at institution of treatment)

Thus the results in a have been obtained by Wh BR and Tr treatment of 3 series which were in respect to pts age and stage of disease at institution of treatment very different – heterogeneous The results in b have been obtained by treating groups of patients (A II groups) almost uniform in these respects those in c by treating 3 entirely identical series composed like the Wh series

If now we transfer the percentage results from *all* six groups of the *traction* series to the corresponding patient groups in the *wheelchair* series it is possible to find the number of patients in each of the six groups of *the wheelchair series* who would have obtained a good result i e a normal spherical head by traction By addition this number may be found for the total wheelchair series – and thereby the percentage of NORM sph that would have been obtained *if the total wheelchair series had been treated by traction* In the same way it is possible of course to calculate the result that would have been obtained by bed rest treatment of the wheelchair series

Hereby we have ascertained how one series of a given composition and of considerable size like the wheelchair series

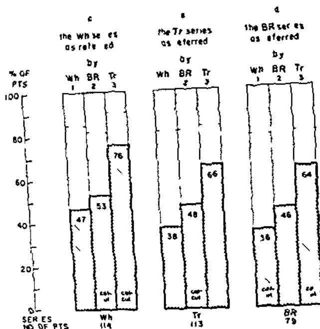


Diagram 9 Radiological results of treating

c	1	*the Wh series as referred by Wh*	(SPH "	85 %)
	2	*the Wh series as referred by BR (calculated)*	(	82 ")
	3	*the Wh series as referred by Tr (calculated)*	("	91 %)
e	1	*the Tr series as ref rred by Wh (calculated)*	(SPH	82 %)
	2	*the Tr series as referred by BR (calculated)*	(	82 %)
	3	*the Tr series as referred by Tr*	("	84 %)
d	1	*the BR series as referred by Wh (calculated)*	(SPH	79 %)
	2	*the BR series as referred by BR*	("	73 %)
	3	*the BR series as referred by Tr (calculated)*	(	80 %)

(A total tabulation of the radiological results is given in the Appendix Table 27 Re group c cf legend of Diagram 8. Abbreviations and symbols on p 1)

will respond to *three different treatments* In other words the three results are comparable expressing the different efficacy of the three therapeutic methods in *one* series – or if you will in *three* identical series – of a composition like the wheelchair series

Of course it may be calculated in the same way what the three treatments could have effected in *the traction series* and in *the bed rest series*

Diagrams 8–9–10 set out the results of these calculations (showing for comparison the results in the series as referred and their A_{II} groups)

It is evident that the results of the three methods of treatment in the wheelchair series do not differ essentially from those in the A_{II} groups (Diagram 8) Only the difference between the results of traction and wheelchair treatment are somewhat less marked than in the A_{II} groups simply because the differences in the light and heavy groups now included are less than in the A_{II} groups (Diagram 4) and therefore reduce the difference in the total wheelchair series On the other hand the difference between the results of *bed rest* and *wheelchair* treatment are not inferior

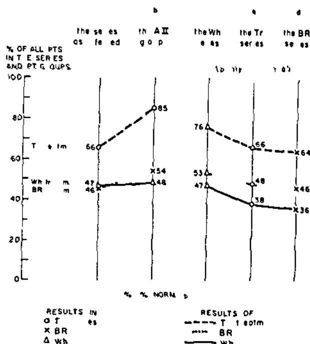


Diagram 10 Survey of the radiological results set out in Diagrams 8 and 9 (but excluding % SPH)

On this survey diagram each set of 3 columns from Diagrams 8 and 9 is replaced with a more simple symbol a vertical line

The 3 small symbols on the vertical lines signify the results in the 3 series as referred and their A II groups

The oblique lines between the vertical ones connect the results of the same form of treatment

(A total tabulation of the radiological results is given in the Appendix Table 27 Abbreviations and symbols on p 12)

to those in the A_{II} groups Calculation of the differences in the traction and bed rest series even shows them to be somewhat greater (Diagrams 9–10), because the dif ferences between the results in the other groups with bed rest and wheelchair treat ment were *not* less than those in the A_{II} group On the contrary the difference is most marked in group B_I (Table 7)

Thus the results of the three methods of treatment in the *wheelchair* series did not differ essentially from the results in the A_{II} groups When calculated for the *traction* and *bed rest* series on the other hand the results of the three methods of treatment are on the whole somewhat inferior to those in the wheelchair series simply be cause these are heavier series – the bed rest series most severe (Diagrams 9–10) How ever, as in the wheelchair series, the relative values of the results correspond quite well to those found in groups A_{II}

In other words The deviations from the results in the A_{II} groups found by in cluding the results in all groups in the analysis are fully explained by the differ ence between the A_{II} groups and the total series

The result of the calculations then, has given no reason to believe that the results in the A_{II} groups are characterized by chance because of too small numbers of patients According to the finding, the results in *the* A_{II} *groups afford* a reliable impression of the effect of the three treatments as to the radiological result in a group of medium severity

It now remains to be seen whether the other source of uncertainty in analysing the results in the A_{II} groups – the heteroge neous sex ratio in the groups – has appreciably affected the results

This uncertainty naturally applies to all results in groups and series comprising both sexes (mixed) Therefore the study was carried out in the way that all analyses and calculations in such mixed series were performed *on boys only* Thereafter the results were compared with those in mixed groups

As the therapeutic results are somewhat more favourable in boys than in girls a study on boys alone would be expected to show rather better therapeutic results – and perhaps altered differences in results between the three treatments

Diagrams 11 12 and 13 as well as Tables 8 and 9 show that in all essentials they did

But the percentage of NORM sph for boys alone in the wheelchair series is nevertheless not essentially better than in the corresponding mixed groups of pa tients This is because in the wheelchair series the results were equally good for girls and for boys In the traction and bed rest

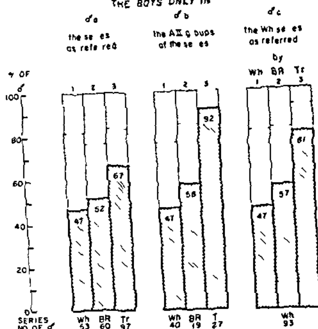


Diagram 11 Radiological results of treating the BOYS alone in

♂a	1 the Wh series as referred by Wh	(SPH	82 %)
	the BR series as referred by BR	(	77 %)
	3 the Tr series as referred by Tr	(	84 %)
♂b	1 the A II group of the Wh series by Wh	(SPH	77 %)
	2 the A II group of the BR series by BR	(	85 %)
	3 the A II group of the Tr series by Tr	(	100 %)
♂c	1 the Wh series as referred by WH	(SPH	82 %)
	2 the Wh series as referred by BR (calculated)	(	83 %)
	3 the Wh series as referred by Tr (calculated)	(	93 %)

% S / % NORM sph

(1 and 3 signify Wh BR and Tr treatment respectively)

For comparison Diagram 8 shows the results of treating GIRLS + BOYS in the corresponding mixed series and groups of patients

(A total tabulation of the radiological results is given in the Appendix Table 27 Abbreviations and symbols on p 12)

Statistical calculations concerning the results of treating BOYS only

There was a significant difference in the frequency of patients with normally spherical heads (NORM sph) between

the ♂A II groups of the Tr series and Wh series ($p < 0.001$) and

the ♂A II groups of the Tr series and BR series ($p < 0.02$)

Moreover there was a significant difference in the frequency of pts. with spherical heads (SPH) between the ♂A II groups of the Tr series and the Wh series ($p < 0.05$)

series on the other hand the results were poorer for girls than for boys so that the results were improved by omitting the girls

Thus the boys A_{II} groups are uniform with regard to age and stage at institution of treatment as well as sex – the factors apart from the treatment which determine the results

More uniform groups of patients cannot be set up

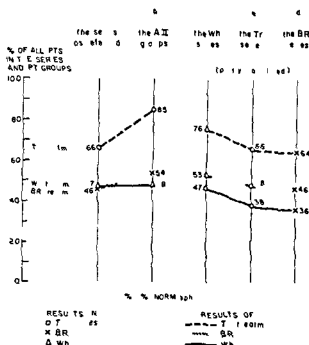


Diagram 10 Survey of the radiological results set out in Diagrams 8 and 9 (but excluding % SPH)

On this survey diagram each set of 3 columns from Diagrams 8 and 9 is replaced with a more simple symbol a vertical line

The 3 small symbols on the vertical lines signify the results in the 3 series as referred and their A II groups

The oblique lines between the vertical ones connect the results of the same form of treatment

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to those in the A_{II} groups Calculation of the differences in the traction and bed rest series even shows them to be somewhat greater (Diagrams 9–10) because the differences between the results in the other groups with bed rest and wheelchair treatment were *not* less than those in the A_{II} group On the contrary the difference is most marked in group B_I (Table 7)

Thus the results of the three methods of treatment in the *wheelchair* series did not differ essentially from the results in the A_{II} groups When calculated for the *traction* and *bed rest* series on the other hand the results of the three methods of treatment are on the whole somewhat inferior to those in the wheelchair series simply because these are heavier series – the bed rest series most severe (Diagrams 9–10) However, as in the wheelchair series, the relative values of the results correspond quite well to those found in groups A_{II}

In other words The deviations from the results in the A_{II} groups found by including the results in all groups in the analysis are fully explained by the difference between the A_{II} groups and the total series

The result of the calculations, then has given no reason to believe that the results in the A_{II} groups are characterized by chance because of too small numbers of patients According to the finding the results in *the* A_{II} *groups afford* a reliable impression of the effect of the three treatments as to the radiological result in a group of medium severity

It now remains to be seen whether the other source of uncertainty *in analysing the* results in the A_{II} groups – the heterogeneous sex ratio in the groups – has appreciably affected the results

This uncertainty naturally applies to all results in groups and series comprising both sexes (mixed) Therefore the study was carried out in the way that all analyses and calculations in such mixed series were performed *on boys only* Thereafter the results were compared with those in mixed groups

As the therapeutic results are somewhat more favourable in boys than in girls a study on boys alone would be expected to show rather better therapeutic results – and perhaps altered differences in results between the three treatments

Diagrams 11 12 and 13 as well as Tables 8 and 9 show that in all essentials they did

But the percentage of NORM sph for boys alone in the wheelchair series is nevertheless not essentially better than in the corresponding mixed groups of patients This is because in the wheelchair series the results were equally good for girls and for boys In the traction and bed rest

fluctuations are less marked (Diagram 11) (cf also p 23)

The results of the three treatments of the boys in each of the three total series – wheelchair bed rest and traction series – bore exactly the same relationship to the results in the boys A_{II} groups as did the corresponding results in the mixed total series to the results in the mixed A_{II} groups (Diagram 13) (For statistical calculation concerning the results in boys only cf legend to Diagram 11 and survey in the Appendix Table 28)

Now it has been attempted to control the drawbacks which indubitably attach to the *mixed* A_{II} groups – the small number of patients and the varying sex ratio – and which have distorted the results found in these groups In part it has been attempted to base the analyses on a larger number of patients all *patients in the total series* – and in part the studies have been carried out *solely on boys*

True the results have shown divergences from those found in the mixed A_{II} groups but in all essentials such divergences have been explicable a a consequence of the different nature of the various patient groups – more mild and severe cases in the total series the milder disease in the boys as compared with the girls

It may therefore be rightly concluded that the results in the mixed A_{II} groups afford by and large a reliable impression of the relative efficacy of the three therapeutic methods in these groups of patients

Wheelchair bed rest and traction give

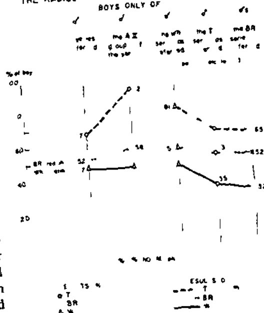


Diagram 13 Survey on all radiological results of treating BOYS set out in Diagram 11 (♂a ♂b ♂c) and Diagram 12 (♂c ♂e ♂d) (excluding % SPH)

On this survey diagram each set of columns from the two diagrams has been replaced with a more simple symbol a vertical line

The 3 small symbols on the vertical lines signify the results in the boys of the 3 series as referred and in their ♂A II groups.

The oblique lines between the vertical ones connect the results of the same form of treatment

For comparison Diagram 10 gave the corresponding results of treating GIRLS + BOYS i.e the results in the mixed series and groups.

(A total tabulation of the radiological results is given in the Appendix Table 27 Abbreviations and symbols p 12)

48 % 54 % and 85 % NORM sph respectively

Table 8 Si of the age/stage groups at institution of treatment The BOYS of the three series (No of boys cf Appendix Table 6)
% of all boys in the series.

Boys	Age/stage groups					
Series treated by	A I	A II	A III	B I	B II	B III
	%	%	%	%	%	%
Wheelchair (93 pts.)	23	43	4	11	17	2
Bed rest without traction (60 pts.)	5	32	13	17	27	7
Traction in bed (97 pts.)	12	28	14	14	26	5

RADIOLOGICAL RESULTS OF TREATING
THE BOYS OF

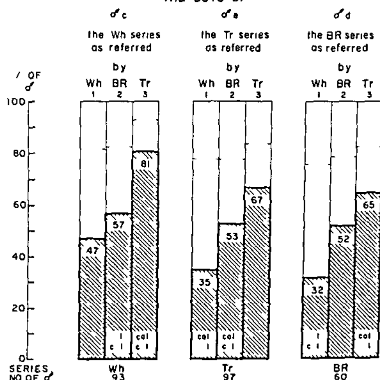


Diagram 12 Radiological results of treating the BOYS of

♂c	*1 the Wh series as referred by Wh*	*(SPH*	*82 %)*
	2 the Wh series as referred by BR (calculated)	*(*	*83 %)*
	3 the Wh series as referred by Tr (calculated)	*(*	*93 %)*
♂e	*1 the Tr series as referred by Wh (calculated)*	*(SPH*	*78 %)*
	2 the Tr series as referred by BR (calculated)	*(*	*78 %)*
	3 the Tr series as referred by Tr	*(*	*84 %)*
♂d	*1 the BR series as referred by Wh (calculated)*	*(SPH*	*76 %)*
	2 the BR series as referred by BR	*(*	*77 %)*
	3 the BR series as referred by Tr (calculated)	*(*	*83 %)*

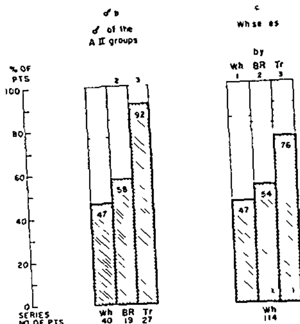
% SPH
% NORM sph

The results of treating GIRLS + BOYS in the mixed series were given in Diagram 9

(A total tabulation of the radiological results Appendix Table 27 Abbreviations and symbols cf survey p 12)

Therefore the results in these groups ought to afford the *most reliable impression of the relative efficacy of the three methods of treatment* in these special groups of boys – more reliable than the results in the less uniform mixed A_{II} groups

Wheelchair bed rest and traction treatment in the *A_{II} groups of boys* gave *47 % 58 % and 92 %* NORM sph respectively The differences are somewhat more pronounced than in the *mixed A_{II} groups (48 % 54 % and 85 %)* The natural explanation is that the girls make up the heavy end of the mixed groups and therefore dampen the differences in the therapeutic results It should be mentioned that in these optimally comparable groups the changes in the SPH percentage follow those in the NORM sph from the traction series through the bed rest series to the wheelchair series only the



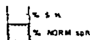


Diagram 14 Radiological results of Wh BR, and Tr treatment in

♂b The prognostically most uniform groups of patients in the 3 series the ♂A II groups. (Results fo nd – st tistical assessment cf Diagram 11)

c One series – or 3 identical ones – composed like the Wh se ies (Results of BR and Tr treatment calcu lated)

These two diagrams afford the simplest impression of the relative efficacy of the 3 methods of treatment (A total tabulation of the radiological results is given in the Appendix Table 27)

hand disclosed that the SPH percentage was considerably higher with traction than with wheelchair and bed rest treatment With the use of the *three therapeutic methods* in *one* series composed like the *wheelchair* series the differences were least marked in the total series viz 85 % 82 % and 91 % on wheelchair bed rest and traction respectively Somewhat greater dif ferences were found on treatment of only the boys of the wheelchair series (82 % 83 % 93 %) and the most marked differ ences on treatment of the *boys* AII group

77 % 84 % 100 % SPH

In the last group the percentage of SPH after traction (100 %) was then 30 % higher than after wheelchair treat ment (77 %) – a difference which is statis tically significant ($P < 0.05$)

All considered however the difference between the results as measured by SPH is smaller than that measured by NORM sph

This is not surprising

If we reduce the demands on a good result to such an extent that they are fulfilled by the majority possibly all pa tients of the three series the differences

The fact that the differences observed in the relative efficacy of the treatments is naturally explained by the different nature of the patient groups must strengthen confidence in the present results It de monstrates also that statements concerning efficacy must be accompanied by informa tion as to *which* series they apply For instance, it must be pointed out that in the mixed A_{II} groups the efficacy values apply only to these rather special groups and that the theoretically more reliable values in the boys A_{II} groups – 47 % 58 % and 92 % NORM sph ' after wheelchair, bed rest, and traction respectively – apply only in these even more special groups

Therefore most interest attaches to the relative efficacy of the three therapeutic methods in each of the three mixed total series – as referred It is in series like these that the treatments should stand their test and accordingly the results in such series are of direct practical significance

In orthopaedic departments in this coun try the cases of LCPD referred will be of approximately the same nature with regard to age and stage at institution of treatment as the three series of the present study – in some departments milder like the wheel chair series in others more severe like the bed rest series

If, in such a department the clientele is known – and it is not likely to change in nature in the near future – it may be predicted after studying Diagrams 9–10 which results can be obtained by traction and which results are obtainable by wheel chair or by bed rest treatment

Briefly

If the material referred is of the same nature as the present wheelchair series *wheelchair* or *bed rest* therapy will afford about 50 % "good" results ('NORM sph ') *traction* about 75 %

If the materials are of a somewhat heavier nature – like the bed rest or traction series – the results will be some-what less favourable but their relative size will be the same

The concrete values for the three ef ficacies in the wheelchair series are

47 % 54 % and 76 % "NORM sph

on wheelchair, bed rest and traction treat ment respectively

These values – and the corresponding results in the bed rest and traction series – are the most perspicuous and in practice the most important result of the studies in the preceding radiological sections

With respect to group SPH it may be added

The size of this group is recorded on all diagrams simultaneously with that of NORM sph ' with a view to the possibili ty of reducing the demands on a good radiological result using SPH instead of NORM sph as a criterion of the percen tage of good results

In the mixed series of different severity, as referred the differences in the results in terms of the percentage of SPH " were not marked in the wheel chair and traction series the results were the same The analyses in the present chapter on more uniform groups of patients on the other

Table 9 Results of treatment of age/stage groups in the BOYS of the wheelchair bed rest and traction series (For No of pts in the groups cf Appendix Table 26)
% = % NORM sph in the groups

Boys	Age/stage groups					
Series treated by	A I	A II	A III	B I	B II	B III
	%	%	%	%	%	%
Wheelchair (93 pts)	81	47 5	0	40	25	0
Bed rest without traction (60 pts)	67	58	37 5	70	37 5	50
Traction in bed (97 pts)	100	92	21	71	56	20

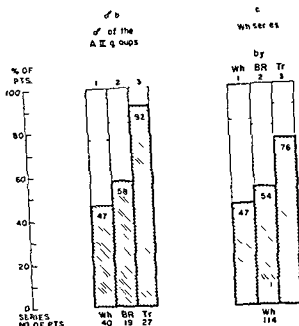
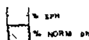


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If the materials are of a somewhat heavier nature – like the bed rest or traction series – the results will be somewhat less favourable, but their relative size will be the same

The concrete values for the three efficacies in the wheelchair series are

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RADIOLOGICAL RESULTS OF TREATING

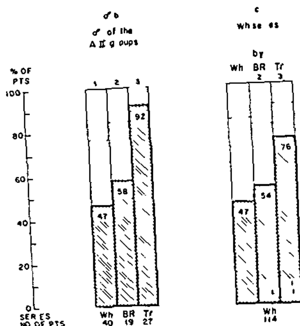
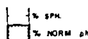


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In the last group the percentage of SPH after traction (100 %) was then 30 % higher than after wheelchair treat ment (77 %) – a difference which is statis tically significant ($P < 0.05$)

All considered however the difference between the results as measured by SPH is smaller than that measured by NORM sph

This is not surprising

If we reduce the demands on a good result to such an extent that they are fulfilled by the majority possibly all pa tients of the three series the differences

between the results will be slight, possibly 0 The same applies of course, if stricter demands are made on a good result so that only a few, perhaps no patients can fulfill them In that case too the difference between the results will be slight possibly 0

But if we use a criterion which entails a borderline between satisfactory and unsatisfactory results in the middle of the series — as when using the criterion "NORM sph" — differences if any between the results obtained will be most clearly apparent

However, a criterion of a satisfactory radiological result is not set up for the purpose of demonstrating the greatest possible difference between the results obtained but exclusively with a view to ascertaining whether the *clinical result* corresponding to the radiological criterion is considered satisfactory Above the radiological criterion 'NORM sph' has been maintained as the one which most dependably leads to a satisfactory clinical result In the following clinical sections it will be discussed whether this is too strict and whether the group SPH' in fact comprises only patients having in practice a good and satisfactory clinical prognosis However this does not seem likely, considering the appreciable articular deformities in the group (Fig 1)

When using the most reliable radiological criterion of a satisfactory clinical result – the percentage of "NORM sph" – the main result of the radiological sections is (highly simplified)

In groups of patients selected from the three series as having the most uniform prognosis, treatment by traction afforded about 80–90 % satisfactory results bed rest and wheelchair treatment about 50–60 % – according to the nature of the uniform groups

In a series of a composition like e g the wheelchair series it may be predicted that traction will afford about 75 % bed rest and wheelchair treatment about 50 % satisfactory results

A collected survey of all the radiological results is given in the Appendix Table 27

The group NORM sph was singled out from the series by means of three quotients, determined by three measuring methods Therefore the assessment may be called a 3 quotient assessment As to the possibilities of using a simpler 1 quotient assessment based solely upon one measuring method cf Appendix Comment 2

8 CLINICAL CONSEQUENCES OF THE RADIOLOGICAL RESULTS

Introduction

The analyses in the present section are based mainly upon reports in the literature – in particular those dealing with follow-up studies of LCPD series and the development of secondary osteoarthritis in general

Unfortunately the data given in such reports are often incomplete and partly irrelevant with regard to the present problems *And – even worse – percentages and other values carry considerable uncertainty* They are seldom based upon precise definitions and the substantiation may leave much to be desired

Therefore the entire present section is interpretable only as an experiment – an attempt at giving a picture of the development of secondary osteoarthritis on the basis of the available reports

(Should the result be unsatisfactory the analyses will at least demonstrate which shortcomings are responsible)

1 Follow up Findings of Osteoarthritis in LCPD Series

In analysing the late sequelae *to LCPD the first thing to be done is to trace the studies* having the longest *follow-up period. I* succeeded in finding only *5 reports* on follow up studies conducted 25 years or longer after the institution of treatment – and in some cases the onset of the disease (Appendix Charts 1–2 *age group III* Nos 1–5)

The follow up period on these cases may seem long – averaging 30–35 years – but nevertheless the patients mean age at follow up has been only about 40 years The dispersion is moderate About two-thirds of the patients have usually been 40 years ± 5 – or possibly ± 7 years in series referred during an unusually long period (Danielsson & Hernborg) Thus it is no great error saying – for the sake of brevity – that in these series patient age was around 40

This mean age is unfortunately not as advanced as might be desired So-called *primary* osteoarthritis in persons with no previous disease of the hips usually manifests itself by the first symptoms at the age 50–70 rarely before 50 at an average age of about 55–60 (Danielsson 1964 55 years) Strangely enough it is usually stated that secondary osteoarthritis – often a sequel to *congenital* articular disease – indeed seems to manifest itself somewhat earlier than the primary type but rarely more than –10 years earlier i e at a mean age of [illegible] –

[illegible] therefore [illegible] patients [illegible] [illegible] [illegible]

between the results will be slight possibly 0 The same applies, of course if stricter demands are made on a good result, so that only a few, perhaps no patients can fulfill them In that case too the difference between the results will be slight, possibly 0

But if we use a criterion which entails a borderline between satisfactory and unsatisfactory results in the middle of the series – *as when using the criterion* "NORM sph" – differences if any, between the results obtained will be most clearly apparent

However a criterion of a satisfactory radiological result is not set up for the purpose of demonstrating the greatest possible difference between the results obtained but exclusively with a view to ascertaining whether the *clinical result* corresponding to the radiological criterion is considered satisfactory Above the radiological criterion 'NORM sph has been maintained as the one which most dependably leads to a satisfactory clinical result In the following clinical sections it will be discussed whether this is too strict and whether the group 'SPH in fact comprises only patients having in practice a *good and satisfactory clinical prognosis* However this does not seem likely considering the appreciable articular deformities in the group (Fig 1)

When using the most reliable radiological criterion of a satisfactory clinical result – the percentage of NORM sph' – the main result of the radiological sections is (highly simplified)

In groups of patients selected from the three series as having the most uniform *prognosis, treatment by traction afforded* about 80–90 % satisfactory results bed rest and wheelchair treatment about 50–60 % – according to the nature of the uniform groups

In a series of a composition like e g the wheelchair series it may be predicted that traction will afford about 75 % bed rest and wheelchair treatment about 50 % satisfactory results

A collected survey of all the radiological results is given in the Appendix Table 27

The group NORM sph was singled out from the series by means of three quotients, determined by three measuring methods Therefore the assessment may be called a 3 quotient assessment As to the possibilities of using a simpler 1 quotient assessment based solely upon one measuring method cf Appendix Comment 2

comprises about 25–50 % of the total patients in a series If the percentage of SPH increases beyond 50 % the share of NORM sph will rise maybe up to the 100 % found in a normal material If the percentage of SPH is below approx 25 % the share of NORM sph drops right down to 0 In a series in which the result is very poor (SPH <7–10 %) there will be only cases healing with abnormally shaped femoral heads viz the groups PATH sph and NON sph – perhaps even only cases with irregular non spherical heads (NON sph)

In Helbo s series in which the group SPH made up only 12½ % only five patients had an *epiphyseal* quotient >60 and it is doubtful whether any of these patients had a *joint surface* quotient >85 and a *radius* quotient <115 In other words it is questionable whether this series contained any case of the group NORM sph

But when relating the results in the many series to each other it is of course also of the utmost importance that not only the primary deformities but also the concepts *radiological osteoarthritis* and *clinical symptoms* have been accurately defined so that we know what we are talking about

Regrettably this wish is rather deficiently fulfilled in the majority of reports The term radiological osteoarthritis is defined with some accuracy by only one author (Danielsson) Most authors seem to take it for granted that there is general agreement concerning the signs of radiological osteoarthritis and this is far from being so For instance Danielsson did not interpret osteophytes as a sign of osteoarthritis whereas Wiberg (1939) considers them important In return Wiberg did not consider increased density of skeletal structure as seen in the acetabulum in acetabular dysplasia and subluxation a sign of osteoarthritis but a reactive skeletal change and thus a precursor of osteoarthritis

The most reliable *radiological sign* of osteoarthritis is probably narrowing of the joint space But even this is a subject of discussion and its frequency is mentioned in only two of the many series Danielsson & Hernborg s and Gower & Johnston s

However it must be pointed out that all the signs of radiological osteoarthritis are objectively demonstrable phenomena There may be disagreement concerning the significance of the individual components and in mild cases about the diagnosis However when several or all components are present there is usually not any major disagreement about the diagnosis Accordingly statements about the occurrence of radiological osteoarthritis at follow-up carry considerable objective accuracy

This applies far less to the *clinical manifestations*

Clinical manifestations refer preliminarily to all clinical symptoms from the hip whether their cause is primary articular deformity or secondary osteoarthritis

They consist in *objective signs* and *subjective complaints* The former rarely give rise to disagreement On the other hand assessment of the latter as indicated by the name is highly subjective What one patient considers a trifle may be a severe complaint to another Some doctors having an optimistic attitude tend to minimize the patients complaints especially when unexplained by objective findings while others attach much importance to the slightest complaints

This uncertainty is all the more unfortunate as it is the subjective complaints and their influence upon the patients lives that are of most interest in our context

Despite the uncertainty however some main features concerning the subjective clinical symptoms may be deduced from the literature listed (*vide infra*)

The frequency of radiological osteoarthritis as well as of clinical manifestations has usually been stated as the percentage of all patients in the series This requires a few

were over 50 (30 in all) In Ratliff's material (5) the oldest patient was 52

On the other hand, there have been many follow up studies with a shorter follow up period a *mean patient age of only 20–25* Seven of these studies are included in the present analysis, because they afford data suited for elucidating the development during the years between primary healing and the age of about 40 (Appendix, Charts 1–2 *age group II* Nos 6–12)

The state at *primary healing* is elucidated by the three series of the present study Mose's series that received ambulatory treatment, and another three series from the literature (Charts 1–2 *age group I* Nos 13–19) This group includes only series in which the radiological deformity was determined *by measurements* on the X ray films

Thus the entire analysis comprises 19 series (Numbers and abbreviated names of authors as listed in the Appendix Chart 1 will be used below when expedient)

The object of analysing these 19 series is in brief to establish the relationship between the radiological joint deformity that the disease has left and the subsequent secondary osteoarthritis – its radiological signs as well as the clinical symptoms

But if general conclusions are to be drawn from the analysis of so many series it is a presupposition that the *primary radiological deformities* of the joint can be described according to the same principles in the different materials i e so that the results are comparable

To this end it is essential to determine as far as possible in each series the size of at least one group well defined with a view to primary radiological deformity If this can be done the primary radiological deformities in the series may be compared in broad features

A simple group suited to this purpose is perhaps our *group SPH* – which is moreover of particular interest as regards the development of osteoarthritis

The initial task then, was to try determining the size of this group in the 19 series Of course, this has been possible only with approximation but nevertheless in a way so that the results seem applicable as I hope will be apparent from what follows

Most of the *authors* have grouped their series into three, more rarely into four groups according to the primary deformity of the hip joint, as a rule of the femoral head The groups have received different designations Good fair poor or – with a view to capital shape spherical "flattened', or irregular' (Appendix Chart 4) In all late follow up examinations these groupings have been based on an estimate as already mentioned not upon objective measurements Nevertheless they have been according to certain criteria described by the authors in the text These descriptions – as well as accompanying X ray films and drawings if any – permit a determination of the size of the SPH group without too wide a margin of error I have tried to demonstrate this by a more detailed account of the assessment in the 5 series with the longest follow up (Appendix Comment 3)

The procedure was the same in series 6–12 with shorter follow up periods but a detailed analysis of these series would require too much space

The 7 series used for elucidating the condition at *primary healing* were assessed by *objective measurement* of the articular deformity Therefore the size of the SPH group can be established with far greater certainty In those series in which Mose s plate was used in the assessment the value is simply given as part of the measuring results

It is not possible to assess the size of the NORM sph group in the 16 series from the literature Only it may be said that according to the scanty experience so far of defining this group it makes up about half of the SPH group when the latter

comprises about 25–50 % of the total patients in a series If the percentage of SPH increases beyond 50 % the share of NORM sph. will rise maybe up to the 100 % found in a normal material If the percentage of SPH is below approx 25 % the share of NORM sph drops right down to 0 In a series in which the *result is very poor (SPH <7–10 %) there* will be only cases healing with abnormally shaped femoral heads viz the groups *PATH sph and NON sph* – perhaps even only cases with irregular non-spherical heads (NON sph)

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The *frequency of* radiological osteoarthritis as well as of clinical manifestations has usually been stated as the percentage of all patients in the series This requires a few

comments, considering that one of the objects was to arrive at the proportion of the individual series definitely *without* osteoarthritis

Most authors have classified their series into groups by first imagining the patients placed in one row according to increasing radiological deformity of the joint This row is then divided into three or four groups, *from the least deformed end of the* series to the more severely deformed one A statement thereafter that radiological osteoarthritis was present in 50 % of the patients of course does not mean that radiological osteoarthritis occurred exclusively in the most deformed half of the series in which *all* patients were affected, whereas the remainder were unaffected True osteoarthritis is bound to be most common at the most deformed end , but it will extend also into the less deformed end In brief, the cases will spread over a larger part of the series than indicated by the percentage stated This spread has been recorded by the authors of four out of the *five series having the longest follow up* (Helbo, Sundt Danielsson & Hernborg, Gower & Johnston) and by some of those with a shorter follow up by stating the percentage of radiological osteoarthritis in *each* of the deformity groups *In Ratliff s series and in some series with a shorter follow up period I estimated the spread on* the basis of other data given by the authors – in particular the size of the deformed groups Of course such an estimate of the percentage of the series within which the cases of osteoarthritis are spread will be somewhat uncertain For this reason the estimate was kept at the *lower end* of what is possible and should always be accompanied by the simple percentage of patients with osteoarthritis in the series

The same reasoning applies to stating the percentage *of subjective symptoms in the* series (cf also Appendix Comment 4)

These more general remarks on the procedure of the analysis will now be followed by the results

a *Primary Radiological Joint Deformities – in Particular the Percentage of SPH – in the 19 Series*

Diagram 15 and Charts 4–5 in the Appendix present my estimate of the sizes of group "SPH or the measurements of the various authors in the 19 series related to the authors classifications The very accurate *figures (61 %, 74 %, etc) in the* series not measured might lead one to imagine an accuracy which is of course not present The figures are merely a calculative consequence of the various authors very exact numerical classification which as already mentioned, carries a great uncertainty Examples of how my figures are derived are given in the Appendix Comment 3 The figures are of course used only with due regard to their estimative nature Lastly, Chart 3 presents the treatment which had led to these radiological results

On the diagrams and charts the series are then set up in three groups mainly *according to mean age at follow up*

III 40–45 years II 20–25 years I <20 years

Within each group the series are arranged by increasing percentage of *SPH the lowest at the top*

In the lowest group I the percentage of SPH in all the series was determined by objective measurements on the X ray films in 6 of the 7 series even by the method of Mose In this group therefore the percentage of *SPH can be stated with great* accuracy

In the other two age groups the SPH percentage has been determined mainly in relation to the authors estimated classifications and is therefore considerably more uncertain than in group I An important goal of the studies is to decide with the greatest possible accuracy whether radiological osteoarthritis and subjective complaints occur also in the patients of group SPH Therefore the size of this group

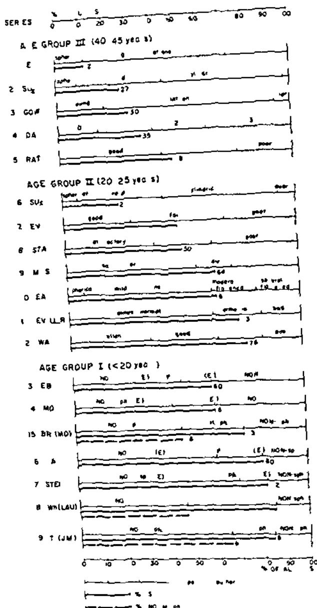


Diagram 15 % "SPH as estimated by J M – or directly measured – in 19 followed LCPD series listed in relation to the classification used by the respective authors mainly according to the degree of primary radiological deformity

In age groups III and II the classifications are estimated

In age group I the classifications are based on measurements on the X ray films and group SPH appears as a direct link in the measured classification. In this group the terms used by the respective authors are replaced with those used in the present study (pp 20 and 36)

The patie ts of the respective series are arranged according to increasing radiological deformity from L to R

(Percentages of the respective authors classification cf Appendix Chart 4

J.M s estimate concerning si e of group SPH cf Appendix Comment 3

For designation of series number of patients patie t age and other data concerning the respective series cf Appendix, Charts 1–3)

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series an increasing percentage of ' SPH 19 % 61 % 77 % and 87 % with in creasingly effective relief from weight bearing

The finding of the same relation in the 16 far less elucidated series from the literature must indicate that the estimated SPH percentages are credible – that they can be regarded as a real expression of *the primary deformation* of the joint left by the disease in these series

b *Radiological Osteoarthritis*

Despite varying views on the radiological signs of osteoarthritis the percentage of radiological osteoarthritis in the series must be considered to carry a considerable objec tive accuracy This is confirmed int al by the development of radiological osteoarthritis in the series from primary healing to the longest follow up showing a definite pattern not characterized by chance

Diagram 16 illustrates the distribution of radiological osteoarthritis in the series when arranged by increasing primary radiological deformity (from left to right) The small circle signifies the percentage of radiological osteoarthritis in the total series

The pattern evident from Diagram 16 is then

Investigation of the series at *primary healing* or shortly after *(group I)* revealed *no radiological* signs of osteoarthritis

At follow-up at an *age of 20–25 years (group II)* mild signs of radiological osteoarthritis had started to manifest themselves in a few of the series In others (the youngest two Nos 8 and 11) such signs are not mentioned either because they were absent or were deemed of no importance Only one of these series (No 6) – that part of Sundt s material which had a follow up period of <25 years after onset of the disease – exhibited radiological osteoarthritis in quite a number of patients (32 %) The explanation is that the patients of this material had received practically no treatment Therefore the disease left primary articular deformities entailing radiological osteoarthritis in an appreciable percentage of the *patients* as early as the follow up examination at a mean age of 23 years

Within Sundt s series the percentage of osteoarthritis is so high that the cases are distributed all over the group NON sph possibly a little into group SPH too *From the viewpoint of* o teoarthritis this series belongs rather to the older age group III

In the other six series of age group II the cases of osteoarthritis were only distributed within the 'heavy part of the NON-sph group viz in the most deformed group of the authors classification not occurring at all in group SPH The distribution of osteoarthritis *in these series is broadly* speaking inversely proportional to the size of group *SPH*

The mean age in age group II of these series is 20–25 years while the range is up to 30–40 However there is but little preponderance of radiological osteoarthritis in patients above the mean age

Regrettably there are no suited materials of a mean age from 25 to 38 years but when the mean age has reached *40–45 years (age group III)* the number of cases having radiological osteoarthritis has increased so far that in four of the five materials *they extend also into group SPH* In this age group too the distribution is broadly speaking inversely proportional to the size of group SPH

As far as may be assessed the cases of *osteoarthritis in SPH* are localized exclusively in PATH sph The NORM sph group seems to be entirely uninvolved

In other words the development of radiological osteoarthritis *in the 19 materials* is simple and clear From no case at primary healing to cases *not only in the* NON-sph group but also in SPH at the latest follow up examinations *(mean*

was set at *the lower end* of the inaccuracy range which is always present This may be difficult For instance, the "SPH percentage in Evans and in Gower and Johnston s series has possibly been set too low, but the data from their papers do not permit a higher minimum value Therefore these two series have to keep their place in the sequence

To ascertain the *age distribution* of the series over the three groups may also be difficult because of incomplete information Besides the age criterion has deliberately not been strictly observed in some cases

Some of the series in age group I maybe belong to group II (Katz Steinhauser Ebach) but were assigned to group I as the SPH percentages in these series – as in the others of group I – have been based *upon objective measurements and therefore* are more reliable than the percentages in group II Reversely, the series of Stamp et al as well as of Evans and Lloyd Roberts perhaps ought to be transferred from group II to group I but they are kept in group II because the SPH ' rate is an estimate and therefore a minimum value

On the whole the grouping of the series in the system was done after thorough reflections and seems to be as reliable as it can be on the basis of the available data

Indeed this is confirmed by a glance at the treatment used in the various series (Appendix Chart 3) As a standard of the *efficacy of a treatment* one may use e g that percentage of patients who have been treated by *effective relief from weight bearing* by ambulatory measures or in hospital (in bed with or without plaster etc) for 1–2 years of course with reasonable regard to the treatment in the remainder of the material

If this criterion is applied to the treatments in the various series the main finding is that the more effective in the above sense the treatment has been the higher the rate of SPH The lower SPH values in age group II and especially in group III as compared with I, are explicable not only by the figures being minimum values In the main, they are due to less effective treatment in the older series However, the rule concerning the dependence of the "SPH ' percentage upon non weight bearing does not apply always

For instance it is surprising as already mentioned, that the SPH rate in Gower & Johnston s series could hardly be set higher than 30 % The reason why this is surprising is that in this series the treatment was apparently rather effective – at least long lasting The explanation is presumably that the series was an *unusually heavy one* i e having an unfavourable prognosis before institution of treatment many patients being over 8 years of age and arriving late for treatment In Ratliff's series too a SPH rate higher than 48 % would have been expected considering *the rather effective* treatment in the majority of the cases I have been unable to elucidate the cause of this apparent disproportion There have also been several series treated by the *same* method but obtaining *different* results e g Evans and Evans & Lloyd Roberts series of in patients Cause The latter series was *particularly light* with respect to the age distribution *no patient being over 8 years* at the institution of treatment

Different treatments in series of *different* severity may also afford the *same* result in terms of the SPH rate This applies *to Lauritzen s wheelchair series* and to my traction series However the results prove to differ very much as measured by the percentage of NORM sph – and also *when measured by the percentage* of SPH when correction is made for the difference in the severity of the series (cf section on radiological assessment)

But on *the whole the rule stands* its test The more patients of the series are treated by long term effective relief from weight bearing the higher the SPH percentage

This is no *novelty In 1966 the present* author found in four carefully studied

c *Clinical Osteoarthritis*

But what about the relationschip of radiological osteoarthritis to clinical osteoarthritis?

What does the radiological osteoarthritis mean to the patients?

This question refers exclusively to the symptoms the purely subjective ones as well as the complaints bound up with the objective signs of disease Objective signs which are *not* noticed by the patients are of no interest in this connection

The complaints consist in pain a limp articular stiffnes limitation of motion fatigue in the limbs on minor exertion etc Thereamongst pain is most apt to be recorded as a complaint at follow up This applies in particular to the *late* follow up studies at which complaints of pain are *predominant and therefore receive most* attention The other subjective complaints are often not recorded or recorded separately so that it is impossible to analyse the number of patients having complaints of one kind or another

The symptoms may be due to two causes *in part the primary articular deformity* left by the disease and in part the *subsequent osteoarthritis* It is an experience that pain and articular stiffness are usually late phenomena occurring in step with the development of radiological osteoarthritis whereas the other complaints are often present *immediately* after healing due to the primary joint deformity In *most cases* however there is a question of a mixed complex of symptoms whose causes may be difficult to elucidate

In the following analysis *all* subjective symptoms will be recorded mild as well as severe regardless of their cause – and thereafter it will be attempted to elucidate their causes

However the causes are of less interest than the percentage and the distribution of the symptoms in the series but even this is considerably more difficult to determine – owing to the subjective nature of the symptoms – than the occurrence of radiological osteoarthritis

Nevertheless a pattern appears on analysing the *subjective symptoms* in the series True it is not as simple as the pattern according to which *radiological* osteoarthritis develops but still – a reasonable explanation can be advanced

As *in the analysis of* radiological osteoarthritis this pattern is most clearly apparent when the materials are analysed from group I examined at primary healing through group II to group III examined at *the mean age of* 40

Age Group I

In the introduction it was established that at primary healing the children were largely symptom free This should not be taken quite literally *as in fact there are* mild complaints In the absence of radiological signs of osteoarthritis at this time the complaints must be due exclusively to the primary deformity of the joint They consist in a mild limp fatigue in the leg after walking for rather a long time etc but pain *is uncommon These complaints will be* disclosed by routine history taking As the children themselves do not attach much importance to them it seems justified to call the condition symptom free at least as a preliminary designation

The reason why these previously ig*nored symptoms are now* attributed with essential importance despite their slight intensity is that their extent in the series is possibly interpretable as a measure of the maximum possible *final extent* of secondary osteoarthritis in the series *concerned*

Indeed such mild complaints were found *among the patients of* most group I series

In analysing the bed rest series and traction series in 1966 I found mild complaints in 22 % of the patients of the bed rest series (Diagram 17 series 15) *and* in 13 % of the traction series These symptoms were *spread over all* radiological

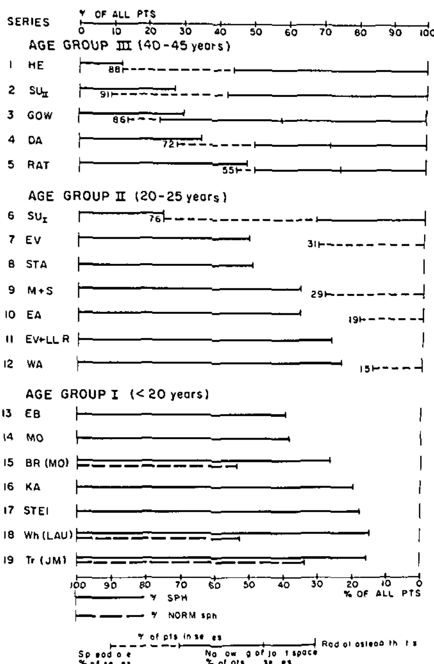


Diagram 16 Radiological osteoarthritis *in 19 LCPD series related to the group SPH (and in a few series to NORM sph)*

Series arranged according to increasing primary radiological joint deformity from L to R

(Magnitude of spread apparent from the authors reports directly or indirectly (cf Appendix Comment 4)

Percentages apart from those listed cf Appendix Table 29 Designation of series cf Appendix Chart 1 Number of patients patient age treatment cf Appendix Charts 2–3 Radiological abbreviations and symbols cf p 12)

age 40–45 years) In the latter group (SPH) there are no doubt cases in the most deformed part of the group – PATH sph – but presumably none in NORM sph The spread of radiological osteoarthritis in the series is broadly speaking inversely proportional to the size of the SPH group

This pattern is very clearly apparent from Diagram 16

c Clinical Osteoarthritis

But what about the relationschip of radiological osteoarthritis to clinical osteoarthritis?

What does the radiological osteoarthritis mean to the patients?

This question refers exclusively *to the* symptoms the purely subjective ones as well as the complaints bound up with the objective signs of disease Objective signs which are not noticed by *the patients are* of no interest in this connection

The complaints consist in pain a limp articular stiffness limitation of motion fatigue in the limbs on minor exertion etc Thereamongst pain is most apt to be recorded as a complaint at follow-up This applies in particular to the *late* follow up *studies at which complaints* of pain are predominant and therefore receive most attention The other subjective complaints are often not recorded or recorded separately so that it is impossible to analyse the number of patients having complaints of one kind or another

The symptoms may be *due to two* causes in part the *primary articular deformity* left by the disease and in part the *subsequent osteoarthritis* It is an ex*perience that pain and articular stiffness are* usually late phenomena occurring in step with the development of radiological osteoarthritis whereas the other complaints are often present immediately after healing due to the primary joint deformity In most cases however there is a question of a mixed complex of symptoms whose causes may be difficult to elucidate

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However the causes are of less interest than the percentage and the distribution of the symptoms in the series but even this is considerably more difficult to determine – owing to the subjective *nature of* the symptoms – than the occurrence of radiological osteoarthritis

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As in the analysis of radiological osteoarthritis thus pattern is most clearly apparent when the *materials* are *analysed from group I* examined at primary healing through group II to group III examined at the mean age of 40

Age Group I

In the introduction it was established that at primary healing the children were largely symptom free This should not be taken quite literally as in fact there *are* mild complaints In the absence of radiological signs of osteoarthritis at *this time* the complaints must be due exclusively to the primary deformity of the joint They consist in a mild limp fatigue in the leg after *walking for rather a long time etc but pain* is uncommon These complaints will be disclosed by routine history taking As the children themselves do not attach much *importance to them it seems* justified to call the condition symptom free at least as a preliminary designation

The reason why these previously ignored *symptoms are now attributed* with essential importance despite their slight intensity is that their extent in the series is possibly interpretable as a measure of the maximum possible *final extent of* secondary osteoarthritis in the series concerned

Indeed such mild complaints were *found among the* patients of most group I series

In analysing the bed rest series and traction series in 1966 I found mild complaints *in* 22 % of the patients of the *bed rest* series (Diagram 17 series 15) and in 13 % of the traction series These symptoms were spread over *all* radiological

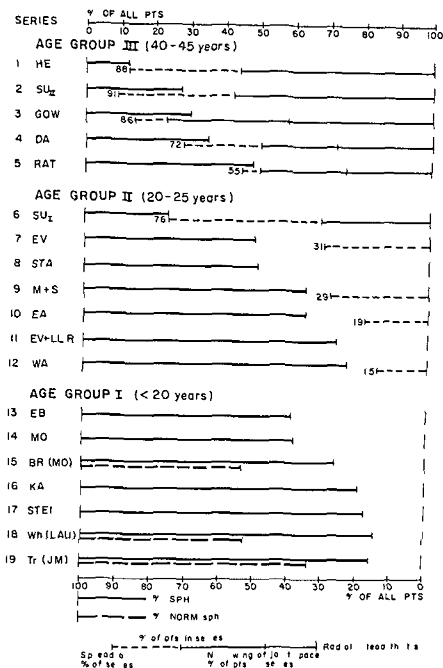


Diagram 16 Radiological osteoarthritis *in 19 LCPD series related to the group SPH (and in a few series to NORM sph)*

Series arranged according to increasing primary radiological joint deformity from L to R

(Magnitude of spread apparent from the authors reports directly or indirectly (cf Appendix Comment 4)

Percentages apart from those listed cf Appendix Table 29 Designation of series cf Appendix Chart 1 Number of patients patient age treatment cf Appendix Charts 2–3 Radiological abbreviations and symbols cf p 12)

age 40–45 years) In the latter group (SPH) there are no doubt cases in the most deformed part of the group – PATH sph – but presumably none in NORM sph The spread of radiological osteoarthritis in the series is broadly speaking inversely proportional to the size of the SPH group

This pattern is very clearly apparent from Diagram 16

the two additional years were not analysed. In Steinhauer's series too (series 17) mild symptoms were reported by 11 % of the patients distributed over 29 % of the series, and in Ebach's (series 13) *in even* 32 % of the patients. In Ebach's series *it is* difficult to ascertain the distribution, but mild complaints were no doubt also present in the patients of group *SPH*.

In the other series there were no doubt also mild symptoms scattered over the groups but they have not been recorded as evidently they have been considered of no consequence.

In general it may be stated that in four of these seven series analysed at a very early date the authors felt it would be reasonable to record mild symptoms. In all series the complaints spread over all radiological groups *also SPH* – in which they were of course rare and slight – occurring even in the group NORM ph where this group could be defined.

Since as already mentioned radiological osteoarthritis could not be demonstrated in these series it is reasonable to deduce that *these* mild complaints have been due exclusively to the joint deformity left by the disease.

Age Group II

In the intermediate age group (group II) there are seven series. However one (series 6) differs so much in subjective symptoms from all the others that *it has to be treated* separately. This is perhaps not so surprising as the occurrence of radiological osteoarthritis in this series was also outside the pattern which otherwise applied to the group.

Accordingly the following refers only to the other six series.

A higher percentage of patients with symptoms had been recorded in two of the series (*Nos 7 and 10*) in age group II than in age group I and three series (7, 10 and 12) even comprised a small group of patients with fairly severe symptoms (marked x in Diagram 17). The *spread* in the series seems largely to be the same as in group I as all these series too showed *symptoms in group* SPH, but the symptoms do seem to be more severe.

This accentuation of subjective complaints in group II may of course be due to a somewhat less sufficient treatment or to a longer follow up period, but the main reason is *probably that now we are no* longer dealing only with primary deformity complaints.

A new element has been added.

At this early age when the patients averaged only 20–25 years *signs of radiological osteoarthritis* were recorded in four of the six series (Nos 7, 9, 10 and 12). All were faint and mild signs restricted to the most deformed part of the series and therefore were far from reaching the same extent as the subjective complaints. No series had radiological osteoarthritis in SPH (Diagram 16).

In other words the subjective complaints in group II show exactly the same spread – some way into SPH – as in group I simply because *it is still the same* category of complaints that determines the spread, the mild deformity complaints. But the main explanation why the symptoms have become accentuated in group II (Diagram 17 x) is the radiologically demonstrable incipient osteoarthritis.

Thus there are two reasons for the complaints in group II, *the joint deformity and the osteoarthritis – but the deformity* complaints still predominate.

However this does not apply to series 6 (SU I). In this series the percentage of subjective complaints is all of a sudden strikingly low and scattered over a relatively smaller part of the series than in all the other series in age groups I and II. *The complaints do not reach into SPH*. This relatively favourable finding is all the more striking as the series is the most poorly treated one within the groups and has an extensive occurrence of radiological osteo-

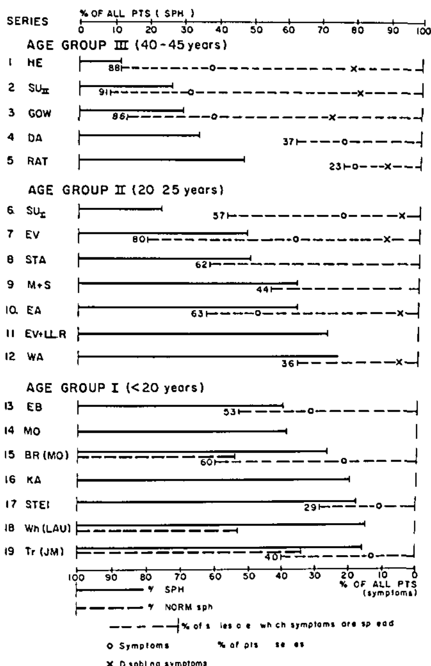
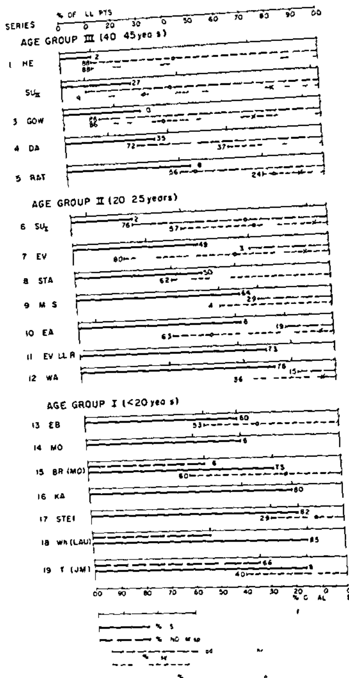


Diagram 17 Clinical symptoms *(cause primary joint deformity or osteoarthritis) in 19 LCPD series set out in relation to the SPH group (or NORM sph)*

Series arranged according to increasing primary radiological joint deformity from L to R

(Spread cf Appendix Comment 4 Percentages apart from those listed cf Appendix Table 29 Designations of series cf Appendix Chart 1 Number of pts patient age treatment cf Appendix Charts 2–3 Radiological abbreviations and symbols cf p 12)

groups – occurring in the traction series even in 4 patients of group NORM sph (6 % of the series) The traction series of the present paper (Diagram 17 series 19) is in all essentials identical with that from 1966 only extended by patients admitted in 1962 and 1963 Therefore subjective symptoms indubitably also occur in the NORM sph group of this series although the symptoms in the patients from



Di gram 18 19 followed LCPD series

Tot l surves

Corr lations between % SPH % r d ological osteoarthritis % cl nical symptoms and the respective authors classification of the series Combination of Diagrams 15 16 and 17

(For pe centages and other d ta apart f om tl ose l sted cf tl ese diagrams Appendix Charts 1–3 and Appendix Table 29)

arthritis quite up to group 'SPH' – a far greater spread of radiological osteoarthritis than all other series of the group (Diagram 16)

Due to these peculiarities the series most naturally ranges with the lowest materials in group III *Therefore, it seems natural to* consider it together with the group III series Thereby, the causes of the apparently peculiar pattern are easier to elucidate

Age Group III

The two bottom series of this group (Diagram 17) show exactly the same peculiarities as did series 6 The percentage of patients with complaints and their spread over the series in relation to 'SPH' is *strikingly lower* than in all the other series None of the three series showed subjective complaints beyond the most deformed radiological groups This is in surprising contrast to the fact that now *radiological* osteoarthritis has extended to the greater part of the *series* right up into group 'SPH' (Diagram 16)

The most reasonable explanation of this change in the picture is that now the symptoms of osteoarthritis have increased so in intensity that *they divert attention from the milder primary complaints which have so far predominated* Of course these mild deformity complaints are still present but they escape registration – like the mild symptoms of osteoarthritis – as attention is riveted on the more outstanding clinical symptoms of osteoarthritis

The fact that this appears in series 6 despite the shorter follow up period is due to the very poor treatment and the consequent considerable primary articular deformity In series 4 and 5 the treatment had been more effective but the follow up period longer – and the result is the same

In the three series at the top (1 2 and 3) we have got to the stage at which subjective complaints are again recorded in a percentage and extent which is relatively the same as in groups I and II into and up to group 'SPH' (In series 2 a limp was used as a measure of subjective symptoms, if pain is used, the extent is somewhat less only 73 % of the series, i e up to group 'SPH') However, the intensity of the *symptoms has essentially increased* manifesting itself in the relatively large groups of fairly severe symptoms in series 1, 2 and 3

In these series with long follow up and insufficient treatment the cases of radiological osteoarthritis have evidently developed so far that invariably they give rise to subjective symptoms of an intensity great enough to be recorded The milder primary deformity symptoms are no longer recorded

The pattern of the development of subjective symptoms in the 19 series may then be described as follows

In all series from the shortest to the longest follow up periods (with three exceptions) there is the same relative extent – spread – of the subjective symptoms in relation to the primary joint deformity They are present in the entire group 'NON sph' and in part of the 'SPH' group – i e at least in the group 'PATH sph' (Diagram 17)

In age group I (<20 years) the symptoms within the spread range are mild and rare – and caused *exclusively by the primary joint deformity*

In age group II (20–25 years) the intensity of the *symptoms within the* spread range have increased Now they are of mixed cause *due partly to the primary joint deformity and partly to incipient osteoarthritis*

Lastly the symptoms in age group III (40–45 years) are the most intense and the most dense ones within the spread range – and they are due *exclusively or predominantly to the ever increasing osteoarthritis*

(The reason why three series (4 5 and 6) apparently fall outside the pattern has been discussed above)

2 Clinical Significance and Calculated Subsequent Development of Osteoarthritis Found in the Series Followed Up

Two problems still await clarification

1 In the above assessment all degrees of severity of radiological and clinical osteoarthritis are included – even the mildest ones No further evaluation of its clinical importance was carried out *How much does it in fact mean to the patients?*

2 Moreover the investigations reviewed above suffer from the deficiency that the development of osteoarthritis has never been followed in an LCPD series longer than up to a mean patient age of 40 years What about the development of the osteoarthritis beyond this mean age?

An attempt will be made to elucidate these two problems

In the three series that had received the poorest treatment (1 2 3) radiological and clinical osteoarthritis (of all degrees of severity) was present at the mean age of 40 in almost two-thirds of the patients – spread over almost 9/10 of the series But it was in only just over 1/5 (22 %) of all the patients that it could be called disabling and at that only to a moderate degree All such cases occurred in the group with the most deformed hip joints viz NON-sph and in only just over one-quarter (28 %) of *the patients* in this group Of all the cases of osteoarthritis only one third (33 7 %) caused symptoms severe enough to be moderately disabling (Diagram 20)

In brief Osteoarthritis was widespread in these series but caused only moderate symptoms

This low intensity of symptoms was in definite contrast not *only to the pronounced* radiological signs but also to the very considerable primary joint deformities in these very series

This then was the appearance of osteoarthritis secondary to LCPD in the follow up of patients in the three series when they had reached a mean age of 40

It is remarkable that for osteoarthritis secondary to other diseases of the hip congenital or arising in childhood the findings are in principle exactly the same

Jerre has reported a follow-up study of 137 patients with a history of slipped femoral capital epiphysis (in 183 hips) during puberty and treated by various conservative methods (Acta orthop scand suppl 6 1950)

Follow up at a mean age of 30 showed frequent and extensive radiological osteoarthritis – 75 % spread over 91 % of the series – accompanied by predominantly mild symptoms of the same extent Only 23 % of the patients had disabling symptoms. This percentage was 22 in the three LCPD series Incidentally the disabling symptoms in Jerre s patients do not seem to have been of serious nature and were present chiefly in those with the longest follow up (mean age 35 years)

Briefly Exactly the same findings as in the LCPD series – only in patients who were on the average 10 years younger

Jerre concluded In the present series taken as a whole the discrepancy between the subjective symptoms and the roentgenological arthrosis deformans was often remarkably large – – – – – (and) this discrepancy was always in one and the same direction namely that the roentgenologically manifest arthrosis deformans was more severe than was expected by the symptoms

This conclusion in its exact wording might be drawn from the late follow-up studies of LCPD series by the three authors (Nos 1 2 3 and with even greater justification by Nos 4 and 5)

It may be objected that it is not permissible to transfer conclusions from the nature and development of osteoarthritis secondary to other diseases of the hip during childhood to osteoarthritis following upon LCPD and that therefore the agreement found is due to chance Such scepticism however is hardly justified In reported studies on the clinical picture of secondary

Thus the analysis in this first clinical section – especially of age group III – has confirmed the preliminary assumption that signs of osteoarthritis, in particular the most reliable *signs viz radiological osteoarthritis develop also in patients in radiological group SPH* – at least in group ' PATH sph

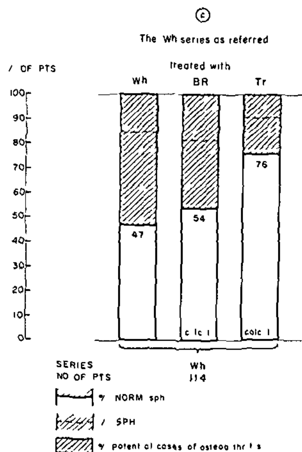


Diagram 19 Extent of potential osteoarthritis in a series composed like the Wh series (114 pts) after 3 possible methods of treatment

(Survey of radiological results (with percentages for SPH) cf Appendix Table 27)

The question now is whether cases of osteoarthritis occur also in *NORM sph*

The mild subjective symptoms which appear to be present in this radiological group already at the time of primary healing might be interpreted as a sign that some patients of the group were potential osteoarthritics However this cannot be confirmed as the group NORM sph cannot be separated in the series in age *group III Only*, it may be said that in these radiologically so *greatly deformed* series the group NORM sph *must be very small* Therefore, cf Diagram 18 the cases *of osteoarthritis* will probably not ' enter this group

This can hardly be excluded – but if patients who will escape osteoarthritis are to be picked out at the time of primary healing there is – according to the findings so far – at least no *major error in selecting the patients* of group *NORM sph and in expecting that patients of PATH sph and NON sph ' are potential osteoarthritics*

Should subsequent follow up studies reveal that all patients of ' NORM sph ' cannot go on escaping osteoarthritis the radiological criteria for cases that escape osteoarthritis may easily be restricted

Finally it may be mentioned that *all* the cases of osteoarthritis observed so far must be designated as secondary having been demonstrated with certainty only in hip joints deformed by disease

Primary osteoarthritis – by definition – occurs only in previously non deformed joints and is rarely diagnosed before the age of 50 Above the age of 50 the incidence is low up to an advanced age According to Danielsson it is only ½ % at 60

But even though there had been a question of persons with previously healthy hips there would not have been any major possibility of encountering a single case of primary osteoarthritis The number of patients is too small and their age is at most around 40

Diagram 18 (and Appendix Table 29) give a survey of the investigations in the present section Diagram 19 exemplifies the extent of potential cases of osteoarthritis in one series after three possible *methods of* treatment

2 Clinical Significance and Calculated Subsequent Development of Osteoarthritis Found in the Series Followed Up

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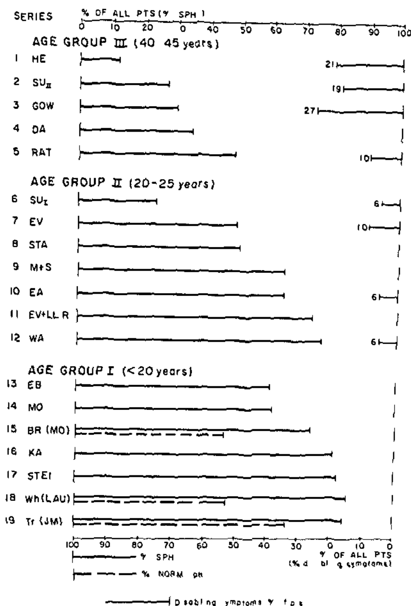


Diagram 20 Disabling symptoms in 19 LCPD series related to the group SPH
The number of cases having disabling symptoms is stated in only 8 of the 19 publications
The series are arranged according to increasing primary radiological joint deformity from L to P
(Percentages apart from those stated cf Appendix Table 29 Designations of series cf Appendix Chart 1 Abbreviations and symbols cf p 12)

osteoarthritis this condition is always considered a characteristic disease whose clinical nature and development (qualitatively) are *independent of its primary cause Its* severity and – to some extent – the time of its onset on the other hand depend upon the degree of the primary joint deformity The symptoms set in somewhat earlier and sooner become more marked in the presence of severe joint deformities However this of course also applies to osteoarthritis following upon *one* disease which leaves different degrees of articular *deformity*

In principle the nature and development of secondary osteoarthritis is the same following different primary causes

Accordingly Jerre s finding that osteoarthritis secondary to slipped epiphysis is strikingly mild clinically in relation to the

radiological lesions supports the validity of similar findings concerning osteoarthritis following upon LCPD

However his series was followed up only to a mean age of 30 Therefore the findings throw no light upon the other problem *The development of secondary osteoarthritis beyond the mean age of 40*

In another study from the literature patients with congenital hip disease were followed up at a mean age of *51 years* with a view to the development of osteoarthritis I am referring to Wiberg s study of patients with *congenital* subluxation and acetabular dysplasia (Wiberg 1939)

Wiberg s study is better suited for eluci*dating the further development of osteo*arthritis Its main drawback is its small size (only 17 patients – 14 girls and 3 boys)

In *the* files *from* two Stockholm hospi tals from the period 1908–1925 Wiberg found 44 patients *(aged 13–60 years)* with definitely diagnosed congenital *subluxation* (or dysplastic acetabulum) but without signs of osteoarthritis

In 1937–38 Wiberg wanted *to examine* these patients to ascertain whether se condary osteoarthritis had developed Regrettably he succeeded in tracing only 16 (to which he added yet another patient in whom the absence of osteoarthritis at primary examination was perhaps in *doubt)*

At follow up in 1937–38 – when their mean age was 51 – all 17 patients had signs of osteoarthritis In two however only radiological signs were present so that they are not included as cases of osteoarthritis *In all cases the radiological* signs were appreciable whereas *little information* is given on the nature of the *clinical mani festations at follow up* – *in* particular their subjective role

Wiberg s 17 *patients* appear *to represent*

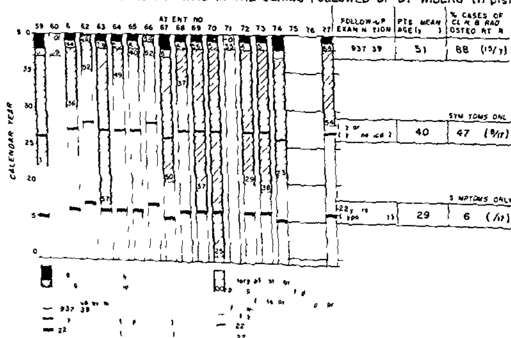


Diagram 21 Development of osteoarthritis in the series followed up by Wiberg (17 pts with subluxation) The result of the follow up examination performed in 1937–39 and the results which would have been found in two hypothetical follow-up examinations 11 years and 22 years earlier

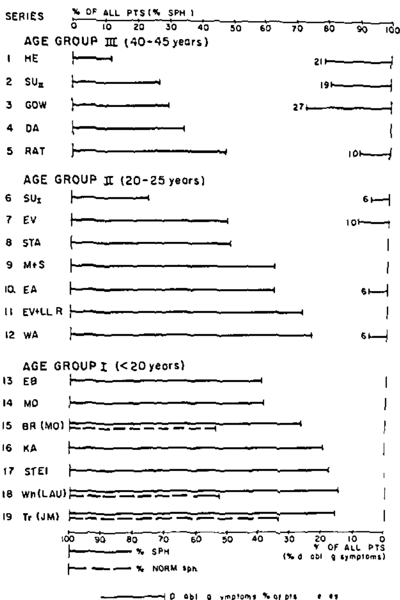


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In principle the nature and development of secondary osteoarthritis is the same following different primary causes

Accordingly Jerre s finding that osteoarthritis secondary to slipped epiphysis is strikingly mild clinically in relation to the

in others none (Diagram 21) A continuous distribution and a distinct pattern would require a larger material

Fortunately the literature contains a report on a far larger material from which corresponding information about the devel opment of secondary osteoarthritis may be deduced – even far beyond the mean age of 40

This series *Ruelle s from 1961* does not afford as many details as Wiberg s but owing to the far larger number of patients the conclusions carry much greater weight

Ruelle reviewed the records for 271 patients who had consulted a rheumatologi cal clinic in the course of some years for secondary osteoarthritis of the hip due to Slipped epiphysis LCPD dislocation and subluxation of the hip etc

For each patient he recorded the onset of what he regarded as clinical symptoms of osteoarthritis Painful limitation of movement in the joint Thereafter like Wiberg he could tabulate the development of secondary osteoarthritis in his material

This is a study of a nature somewhat different f om those reviewed above which were based upon *a given hip disease* congenital or acquired during childhood and designed to investigate the develop- ment of osteoarthritis after this given dis ease Ruelle on the other hand considered the secondary osteoarthritis a well-defined disease entity and regardless of its primary causes he tried to elucidate its develop- ment The causes of osteoarthritis in his material then were manifold – mild to severe deformities of the joints left by *different diseases* – and not as in the studies quoted so far deformities after one well defined hip disease during childhood However the material is so large that Ruelle could divide it up according to the different causes

Still the main advantage of Ruelle s material is its size No other study on secondary osteoarthritis comprises 271 cases

In the material as a whole Ruelle found the values listed in Table 11 and Diagram 22. Unlike the values in Table 10 from Wiberg s study the osteoarthritis rates do not refer to a *mean age* but to the rate of osteoarthritis which the patients had devel oped at the age stated

Ruelle found that about one third (36 %) of the 271 patients developed their subjective symptoms of osteoarthritis be fore the age of 40 and about two-thirds (70 %) before the age of 50 – i e a duplication of the cases within the decade 40–50

Extracting corresponding values from Wiberg s material shows conformity

Just over one third (35 %) of Wiberg s patients developed symptoms of osteo-

DEVELOPMENT OF OSTEOARTHRITIS IN RUELLE s TOTAL MATERIAL (RU I + II)

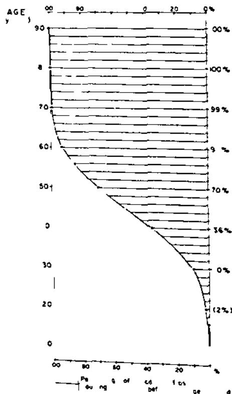


Diagram 22 Development of osteoarthritis in Ruelle s total material (I–II) comprising 271 patients.
Graphic presentation of Table 11 (Cf legend of that table)

a "heavy selection of subluxations As a rule a large number of such patients escape osteoarthritis (Lance) The explanation is possibly that owing to the low follow up rate (17/44) he got hold of mainly those patients who had essential complaints on account of their osteoarthritis

At follow up all the patients were questioned about the *time of onset* of what Wiberg considered subjective clinical symptoms of osteoarthritis Limitation of movement and stiffness in the hip joint with increasing pain All the patients but the two mentioned above were able to state this time with sufficient accuracy

The radiological course is insufficiently elucidated as the patients had not been X rayed regularly during the course

Diagram 21 gives the results

The advantage of this diagram is that it affords information about the percentage of osteoarthritis (subj sympt) that would have been found had the patients been examined *11 years earlier* – i e when they averaged 40 years of age – and if they had been examined *22 years earlier* i e at a mean age of 29 years

The rate of osteoarthritis is shown in Table 10

Table 10 Series followed up by Wiberg (17 pts) Percentage of clinical osteoarthritis at increasing mean age (subjective symptoms)

Mean age (years)	Percentage of osteoarthritis
51	88 %
40	47 %
29	6 %

Thus at follow up when the patients mean age was 40 the osteoarthritis rate (47 %) would have been lower than the mean rate of *all* clinical cases of osteo arthritis in the three LCPD series (64 %) presumably because Wiberg s definition of osteoarthritis is somewhat stricter However it is of course impossible to tell what the radiological and subjective severity of the osteoarthritis was in fact at a mean age of 40

Table 11 Development of osteoarthritis in Ruelle s total material of secondary osteoarthritis (I +II)

This material comprises 271 patients who applied for treatment of symptoms of secondary osteoarthritis of the hip Here then osteoarthritis means clinical osteo arthritis causing symptoms which have sooner or later reached a severity making the patients present themselves for institutional treatment (cf also text and Appendix Comment 5)

% = The percentage of all cases developing symptoms before the ages stated

(The 5–year values are the result of interpolation between the 10–year values found – or fixed graphically on the basis of Diagrams 22 and 23)

(Detailed list in the Appendix Table 30)

Age (years)	%
80	100
75	99 5
70	99
65	96
60	93
55	81
50	70
45	53
40	36
35	23
30	10
25	3 (graphic)
20	2 (graphic)

But it is apparent from the diagram that when the patients had grown 11 years older the percentage of osteoarthritis had almost doubled (47 %–88 %)

From our point of view this is the most important result of Wiberg s study

Whether the clinical severity of the osteoarthritis had increased correspond ingly in the course of the 11 years is not directly stated But reading the follow up data on each patient gives an impression of radiological changes which were at that time on the whole severe and clinical symptoms of a nature which must have given rise to considerable complaints

Wiberg s series however has the essential drawback of being small For instance the onset of the symptoms is very uneven in the course of the years In some years there had been an accumulation of cases –

gations it was found that on the *whole the* development of *secondary* osteoarthritis *was entirely* uniform regardless of the primary cause Slipped epiphysis LCPD subluxation congenital dislocation acetabular dysplasia traumas infection etc Of course the severity of the osteoarthritis may vary as after LCPD but the *pattern of its development is in* all essentials the same

Therefore it was attempted to use the values from the material based upon the largest number of patients and carried up into the oldest age groups viz Ruelle s to gain an idea of the further development of osteoarthritis *in* three of the LCPD *series with the longest follow up periods* (Helbo s Gower & Johnston s and Danielsson & Hemborg s)

However Ruelle s values are not directly applicable to an LCPD series

All patients of Ruelle s series had osteoarthritis (and were presenting themselves for treatment) Thus the osteoarthritis rates at the different ages signify the percentage of the final number of osteoarthritis which in Ruelle s material is equal to *the total number of patients*

But if these values are used for determining the osteoarthritis rate in a given LCPD series at a given time the results also signify the percentage of the *final number* of cases of osteoarthritis in the series If for instance it can be predicted that half the patients of the series are likely to escape osteoarthritis the calculated rates have to be divided into half to apply to the total number of patients in the series

When thus applying Ruelle s values to an LCPD series it is therefore of the utmost importance to know the expected final maximum possible – or likely – percentage of osteoarthtitis in the series

It is this maximum possible osteoarthtitis rate which the present author has tried to establish in the preceding radiological and clinical sections as apparent from the conclusions at the end of the radiological section and from Diagram 19 At the time of primary healing of an LCPD series the risk of osteoarthritis is present only in patients in deformity groups PATH sph and NON sph The size of these groups indicates the maximum part of the series in which final full blown osteoarthritis may occur Osteoarthritis *does not necessarily develop in all patients* within the range – or in them only – but the deviations are not great (Appendix Comment 5)

But are we to use the values from Ruelle s *total series* of secondary osteoarthritis in the attempt at calculating the osteoarthritis rate in the *LCPD* series – *or are values from one of his special subgroups* better suited?

Ruelle divided his material into the following groups according to the primary causes of the osteoarthritis

Ru I Deformities of the head-neck following slipped epiphysis LCPD (only a few) traumas or infection

DEVELOPMENT OF OSTEOARTHRITIS IN RUELLE s TOTAL MATERIAL (I+II) AND IN TWO SMALLER GROUPS OF PATIENTS (I AND IIc)

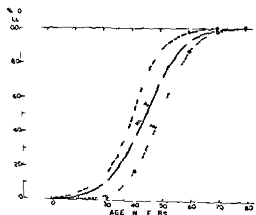


Diagram 23 Development of osteoarthritis in Ruelle s (RU s) total material of secondary osteoarthritis (I + II) and in two smaller groups of patients (IIc and I) having milder and more severe primary joint deformities

The points on the curves indicate the % of all pts – in the total material or in the special groups – in whom symptoms of osteoarthritis set in before the age stated on the abscissa

(P centages and means g of I + II etc cf Table 12 p 60 For further explanations of this diagram cf also Appendix Comment 5)

arthritis before the 38th year of age (6/17) and almost two thirds (65 %) before the age of 51 (11/17) i e very close to a duplication during the age 38–51 (The longer interval 38–51 is due to the irregular distribution of the cases in Wiberg s small material)

As to the clinical severity of the osteoarthritis in Ruelle's series we know only that it caused such inconvenience that *sooner or later the patients applied for treatment* No information is given about the radiological development or about the nature of symptoms existing before the patients presented themselves for treatment

But the pattern of development of osteoarthritis in Ruelle s and Wiberg s series is found also in other studies

The mean age at onset of secondary osteoarthritis was 41 years in Wiberg's material and in Ruelle s it could be calculated to be about 44

In Falconnet and Vignon s series comprising 78 cases of secondary osteoarthritis following subluxation and acetabular dysplasia the first symptoms of osteoarthritis appeared at the mean age of 44 in the patients with subluxation and at 48 years in those with acetabular dysplasia

In Lloyd Roberts series (1955) of 23 cases of severe secondary osteoarthritis requiring operation the first symptoms had appeared at a mean age of 47 In his material of osteoarthritis Danielsson found 18 cases of secondary osteoarthritis of different causes (not subluxation but LCPD coxa vara etc) These 18 patients had noted the first hip pain at a mean age of 44

Lastly it has been reported by Lance that osteoarthritis following upon subluxation begins in the late forties at 45–50 years

This is indeed surprising agreement – all the more so as these uniform results have appeared in studies of widely different age groups Wiberg s mean 51 years Danielsson s 62 years If the spread in the onset of secondary osteoarthritis is no wider than in Ruelle s series – and there is nothing to indicate that it is – these means signify that the onset of secondary osteoarthritis is localized especially, as in Wiberg's and Ruelle s series, within the decade 40–50 years of age

Wiberg, Lance and others have expressed this briefly by stating that in women secondary osteoarthritis develops during and around the menopause and in men a little later

Lloyd Roberts (1955) feels that *primary* osteoarthritis is a disease of the aging rather than old age' stating that the symptoms generally set in at the age of 50–55 years mean 52 5 years rarely sooner or later Danielsson has reported a mean age of 54 7 years at onset of *primary* osteoarthritis

However, Lloyd Roberts view on *primary* osteoarthritis as a disease of the aging may evidently be transferred to *secondary* osteoarthritis – only the latter sets in 5–10 years earlier at an age of 40–50

Thus on the basis of a given series of osteoarthritis it was possible to elucidate in retrospect the development of the osteoarthritis (Ruelle)

If we had a corresponding material of osteoarthritis following LCPD also comprising patients of advanced age it would be possible to elucidate the development of osteoarthritis following LCPD up to a far advanced age

However no such material is available at present

The development of osteoarthritis following LCPD might also be elucidated by following a pure LCPD series up through the years This has not so far been done beyond the age of 40

Accordingly there does not seem to be a possibility at the moment of completely elucidating the development of osteoarthritis after LCPD

But perhaps there is a way out

In Wiberg s Jerre s and Ruelle s investi

gations it was found that on the whole the development of secondary osteoarthritis was entirely uniform regardless of the primary cause Slipped epiphysis LCPD subluxation congenital dislocation ace tabular dysplasia traumas infection etc Of course the severity of the osteoarthritis may vary as after LCPD but the pattern of its development is in all essentials the same

Therefore it was attempted to use the values from the material based upon the largest number of patients and carried up into the oldest age groups viz Ruelle s to gain an idea of the further development of osteoarthritis in three of the LCPD series with the longest follow up periods (Hel bo s Gower & Johnston s and Danielsson & Hernborg s)

However Ruelle s values are not directly applicable to an LCPD series

All patients of Ruelle s series had osteoarthritis (and were presenting themselves for treatment) Thus the osteoarthritis rates at the different ages signify the percentage of the final number of osteoarthritis which in Ruelle s material is equal to *the total number of patients*

But if these values are used for deter mining the osteoarthritis rate in a given LCPD series at a given time the results also signify the percentage of the *final number* of cases of osteoarthritis in the series If for instance *it can be predicted that half* the patients of the series are likely to escape osteoarthritis the calculated rates have to be divided into half to apply to the total number of patients in the series

When thus applying Ruelle s values to an LCPD series it is therefore of the utmost importance to know the expected final maximum possible – or likely – percentage of osteoarthtitis in the series

It is this maximum possible osteoarthtitis rate which the present author has tried to establish in the preceding radiological and clinical sections as apparent from the conclusions at the end of the radiological section and from Diagram 19 At the time of primary healing of an LCPD series the risk of osteoarthritis is present only in patients in deformity groups PATH sph and NON-sph. The size of these groups indicates the maximum part of the series in which final full blown osteoarthritis may occur Osteoarthritis does not necessarily develop in all patients within the range – or in them only – but the deviations are not great (Appendix Comment 5)

But are we to use the values from Ruelle s *total series* of secondary osteoarthritis in the attempt at calculating the osteoarthritis rate in the LCPD series – or are values from one of his *special subgroups* better suited?

Ruelle divided his material into the following groups according to the primary causes of the osteoarthritis

Ru I Deformities of the head neck fol lowing slipped epiphysis LCPD (only a few) traumas or infection

DEVELOPMENT OF OSTEOARTHRITIS IN RUELLE s TOTAL MATERIAL (I+II) AND IN TWO SMALLER GROUPS OF PATIENTS (I AND IIc)

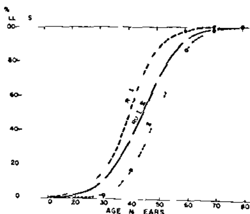


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When thus applying Ruelle s values to an LCPD series it is therefore of the utmost importance to know the expected final maximum possible – or likely – percentage of osteoarthritis in the series

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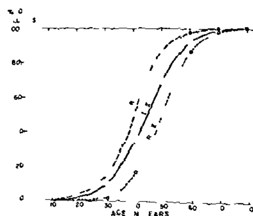


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The po nts on the curves indicate the % of all pts – in the total material or in the special groups in whom symptoms of osteoarthritis set in before the age stated on the abscissa.

(Pe centages a d meaning of I + II etc cf Table 12 p 60 For furthe explanations of this diagram cf also Appendix Comment 5)

Table 12 Development of osteoarthritis in Ruelle s total series (designated I + II) and in the special groups of patients I II a II b + c II c
% = Percentage of all cases of osteoarthritis – in the total material and in the various groups of patients – causing symptoms before the ages stated
As to the designation osteoarthritis cf Appendix Comment 5

	Total material	Groups			
		Sites of joint deformities			
		Head/neck	Acetabulum		
			Congen disloc	Sublux and acetabular dysplasia	Acetabular dysplasia
Ruelle s designation	I + II	I	II a	II b + c	II c
No of pts.	271	68	38	165	170
Age (years)	%	%	%	%	%
80	100			100	100
70	99	100		99	98
60	93	98	100	89	87
50	70	87	90	59	52
40	36	51	58	24	17
30	10	15	21	6	2
Degree of deformity	Moderate	Fairly severe	Most severe	Fairly mild	Mildest

Ru II Acetabular deformities left by (a) congenital dislocation (b) subluxation (c) acetabular dysplasia

True group I does contain cases of LCPD but apparently few – and the group is incidentally of an extremely mixed nature

The group II cases clearly differ in essence from LCPD

In these different groups the osteoarthritis develops according to the same fundamental pattern (Diagram 23 Table 12)

In the total material (I + II) the development of osteoarthritis gradually starts at the age of 30 but does not really gain impetus until the decade 40–50 years thereafter the tempo slows down towards the age of 60 (cf also Diagram 22) In the groups with the most severely deformed joints (e g I) the development is under way already at the age of 30 while in groups with less deformed joints (II c) it does not start until the age of 40 but then continues at an undiminished rate until the age of 60

When considering the groups together the development of osteoarthritis takes place between the ages of 30 and 60 and a particularly rapid rate between 40 and 50 is common to all groups

As it is difficult to assess the relation between the severity of the articular deformities in Ruelle's groups and in the LCPD series with late follow up the osteoarthritis rate for Ruelle s *total material* will be used for the time being for calculating the expected rate of osteoarthritis in the LCPD series

Thereby it is possible to base the calculation upon the largest possible number of patients – and to attain the greatest possible certainty

The procedure is as follows

First the osteoarthritis rate in the LCPD series is calculated at the time of follow up – and this calculated value is then compared with that *found*

If this form of calculation proves satis factory it will be used to form an impres sion of the expected development of osteo-arthritis beyond the time of follow up

This may be exemplified by a brief description of the calculation in the series followed up by Helbo

In his series the patients (47) were *distributed at follow up on the age groups* shown in Table 13

Table 13 Age distribution in Helbo s series at follow-up Mean age 42 years

Age groups (years)	No of pts.
50 60	5
40–50	24
30–40	18

First the calculation in the age group 40–50 years

If the age of all 24 patients in this group is just over 40 the expected osteoarthritis rate in the group will correspond approxi mately to Ruelle s rate at 40 36 % (Tables 11 and 12) But if the majority are closer to 50 the osteoarthritis rate in the group will correspond approximately to Ruelle s rate at 50 70 % As a rule and especially in the middle groups the patients are evenly distributed over the age range 40–50 years and if so the osteoarthritis rate in this age group corresponds approximately to the mean of Ruelle s rates at 40 and 50 i e the osteoarthritis rate at 45 is 53 % (In the extreme groups under 30 and over 60 the mean value has to be corrected a bit (shown graphically in Diagram 23))

According to Ruelle s values then one would expect finding in the age group 40–50 years $\frac{24 \times 53}{100}$ = 13 patients with osteoarthritis

A similar calculation may be performed in the other age groups Addition will show that of all 47 patients of the material 21 will – according to Ruelle – have subjec tive symptoms of osteoarthritis at the time of follow up i e about 45 %

However the presupposition that this value is correct is that *all* patients of Helbo s series are potential osteoarthritics – and they are presumably not According to the review of the literature in the preceding section etc it is predominantly likely that the patients of the primary radiological group NORM sph will escape osteoarthritis – whereas all patients of the other groups are at risk Therefore the percentage size of these groups com bined (PATH sph + NON-sph) ought to indicate the maximum rate of osteo-arthritis in the material

But in Helbo s series – and the other series followed up – the size of the group NORM sph cannot be definitely ascer tained Therefore that part of the series in which there is a risk of osteoarthritis cannot be definitely singled out However major errors are not made – at least not in series having small SPH groups – by fixing the size of the part risking osteo-arthritis by an estimated division of group SPH int al with regard to any spread of osteoarthritic symptoms into this group as *found at follow up* (cf e g Gower & Johnston s series)

In Helbo s series however the size of group NORM sph may be estimated with somewhat greater accuracy as he had measured epiphyseal quotients On that basis the groups PATH sph + 'NON sph were estimated at *95 %* Accordingly the expected rate of osteoarthritis at fol low up is $\frac{45 \times 95}{100}$ = 41 %

Similar calculations may be carried out in Gower & Johnston s and in Danielsson & Hernborg s materials but not in Sundt s (II) and Ratliff's as the age distribution at follow up is not stated

The results are shown in Table 14

It is a common feature to all patients of Ruelle s series that sooner or later after onset of symptoms they *applied for treat ment* in a rheumatic clinic

Table 12 Development of osteoarthritis in Ruelle's total series (designated I + II) and in the special groups of patients I IIa IIb + c IIc

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The results are shown in Table 14

It is a common feature to all patients of Ruelle s series that sooner or later after onset of symptoms they *applied for treatment* in a rheumatic clinic

Table 14 Percentage of osteoarthritis calculated and found at the time of the latest follow up examination in the series of Helbo Gower & Johnston and Danielsson & Hernborg

Values calculated on the basis of those in Ruelle s total material (I + II) the maximum possible osteoarthritis rate being fixed as 95 % in Helbo s series 86 % in Gower & Johnston s and 72 % in Danielsson & Hernborg s.

Author	Calculated: Clinical osteoarthritis (subj sympt)	Found: Clinical osteoarthritis (subj sympt) — Total	Found: Clinical osteoarthritis (subj sympt) — Treatment requiring (Helbo)	Found: Clinical osteoarthritis (subj sympt) — Disabling	Found: Radiological osteoarthritis
	%	%	%	%	%
HE	41	62	34	21	56
GOW	42	61		28	77
DA	28	pain 20 severe compl 17		0	50
HE + GOW + DA	39 6				

The values in Ruelle s analysis (Table 11) are based upon data concerning the *time of onset of the symptoms* but in the summation groups used in the calculation – patients developing osteoarthritis prior to the age of 30 40 50, etc – the symptoms must have started in most cases many years earlier Therefore the majority of patients in the groups have applied for treatment long ago In only a small number of cases the symptoms have set in a short time before the ages for which the osteoarthritis rates were calculated so that at that time the patients have not yet applied for treatment *Regrettably* Ruelle does not give any data regarding the interval between the onset of symptoms and the presentation for treatment

In fact therefore the values in Ruelle s analysis concern patients *the majority of whom had applied for treatment* because *they felt* that their symptoms *required treatment*

Thus if values from Ruelle s material are used for calculating the osteoarthritis rate in a given LCPD series at a given time the calculated rate will *express mainly the percentage of patients who had applied for treatment* – i e patients with ' treatment requiring osteoarthritis *in the sense stated* But as the calculated percentage will include a small number of patients who have not yet applied for treatment it must be expected to be a little higher than the actual percentage of patients who have applied for treatment

In the above analyses of osteoarthritic symptoms found at follow up in various materials all even the mildest symptoms recorded have been included Therefore the stated rate of osteoarthritis is a maximum

From among these cases we can now (possibly) single out a smaller group of patients who had applied for treatment (having treatment requiring osteoarthritis) and from among them an even smaller group with disabling osteoarthritis

In other words the percentage of patients who had applied for treatment will be between that of patients with disabling osteoarthritis and that of all recorded cases

From Table 14 it may be seen that if the values from Ruelle s total series are applied to Helbo s and Gower and Johnston s the *calculated* percentages fit the *found* ones well

In both series the calculated rate of osteoarthritis is *between that of dis abling osteoarthritis* and all recorded cases of osteoarthritis

Helbo even recorded a rate of treat ment requiring osteoarthritis (corre sponding to our term) which is exactly where it would be expected a little lower than the calculated rate viz 34 % as compared with 41 %

In Danielsson s and Hernborg s series it is difficult to compare the calculated and found values because evidently Daniels son s evaluation of the symptoms differs from that in other materials (Diagram 17)

For instance Danielsson and Hernborg s percentage of *all* clinical cases of osteo-arthritis (including a limp 23 %) seems to *correspond largely to Helbo s percentage* of treatment requiring osteoarthritis (cf Appendix Comment 5) – and his percentage of patients with more trou blesome symptoms to Helbo s and Gower & Johnston s percentage of pa tients with disabling symptoms

When this is taken into consideration the calculated osteoarthritis rate (28 %) is in reasonable conformity with the findings in the other two series

From the agreement between the cal culated and found values in Helbo s and Gower & Johnston s series it is apparent that *in fact the development of osteo-arthritis in their series has been like that in* Ruelle s *total material* of secondary osteo-arthritis

But if we apply values from Ruelle s *more severe groups* (e g group I) to Helbo s and Gower & Johnston s series we get calculated rates of osteoarthritis *too high* in relation to those found The fact is that in these groups the development of osteoarthritis starts earlier In the *mild groups* (e g II c) the osteoarthritis devel ops later – and the use of values from these groups will make the calculated osteo-arthritis rates *too low*

It is a presupposition for the above calculation that the patients age distribu tion at follow up is known Only then can the expected rate of osteoarthritis be cal culated on the basis of Ruelle s values If we know the age distribution in the mate rials at follow up we also know the age distribution at *any time before and after* (normal mortality does *not* essentially alter *the age distribution)* – and it *ought to be* easy to calculate the rate of osteoarthritis expected according to Ruelle at any time

This involves int al the possibility of calculating the *future* development of osteoarthritis in the three series with reas onable accuracy When calculation of the osteoarthritis rate in the series more than 25 years after onset of the disease fits the actual one so relatively well calculation of *the future osteoarthritis rate ought to* show reasonable agreement with the develop-ment of osteoarthritis which is going to take place

Therefore such a calculation will be attempted

The procedure is as follows – using Helbo s follow up series as an example

The age distribution in Helbo s series at follow up was as shown in Table 13 When adding 10 years to the age groups we get the age distribution in the material *10 years after the follow-up* (Table 15)

By means of Ruelle s values the rate of osteoarthritis at this time may now be calculated as described for Helbo s series at follow up

Table 15 Age distribution in Helbo s series 10 years after the follow-up examination.

Age groups (years)	No of pts.
60–70	5
50–60	24
40–50	18

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DA	28	pain 20 severe compl 17		0	50
HE + GOW + DA	39 6				

The values in Ruelle s analysis (Table 11) are based upon data concerning the *time of onset of the symptoms* but in the summation groups used in the calculation – patients developing osteoarthritis prior to the age of 30 40 50 etc – the symptoms must have started in most cases many years earlier Therefore the majority of patients in the groups have applied for treatment long ago In only a small number of cases the symptoms have set in a short time before the ages for which the osteoarthritis rates were calculated so that at that time the patients have not yet applied for treatment Regrettably Ruelle does not give any data regarding the interval between the onset of symptoms and the presentation for treatment

In fact therefore the values in Ruelle s analysis concern patients *the majority of whom had applied for treatment* because *they felt* that their symptoms *required treatment*

Thus if values from Ruelle s material are used for calculating the osteoarthritis rate in a given LCPD series at a given time the calculated rate will *express mainly the percentage of patients who had applied for treatment* – i e patients with treatment requiring osteoarthritis *in the sense stated* But as the calculated percentage will include a small number of patients who have not yet applied for treatment it must be expected to be a little higher than the actual percentage of patients who have applied for treatment

In the above analyses of osteoarthritic symptoms found at follow up in various materials all even the mildest symptoms recorded have been included Therefore the stated rate of osteoarthritis is a maximum

From among these cases we can now (possibly) single out a smaller group of patients who had applied for treatment (having treatment requiring osteoarthritis) and from among them an even smaller group with disabling osteoarthritis

In other words the percentage of patients who had applied for treatment will be between that of patients with disabling osteoarthritis and that of all recorded cases

Table 17 Development of clinical osteoarthritis presented for treatment in the series followed up by Helbo Gower & Johnston and Danielsson & Hernborg calculated using figures from Ruelle s total material (I + II) based upon the age distribution at the time of follow up

% % of clinical osteoarthritis in the survivors at the time stated (Appendix Comment 5) Maximally possible osteoarthritis rates HE 95 %, GOW 86 %, DA 72 %.

	Calculated percentage of patients who have applied for treatment with symptoms of osteoarthritis					
	HE		GOW		DA	
	%	Mean age (years)	%	Mean age (years)	%	Mean age (years)
					69	71
30 years later	93	72	85	75	61	61
20 years later	85	62	80	65	46	51
10 years later	67	52	65	55	28	41
At latest follow up examination	41	42	42	45		

Johnston s and in Danielsson & Hernborg s series may be calculated

The total result of the calculations in all three series may be seen in Table 17

Thus if the follow up is repeated 10 years after that which has been performed – when the patients have attained a mean age of 50–55 years – the percentage of patients who had applied for treatment of osteoarthritis in Helbo s and in Cower & Johnston s series must be expected to have increased from about 40 % at a mean age of 40–45 years to about 65 % – or to almost two-thirds of the patients – in Danielsson & Hernborg s material presumably to one half

The development of osteoarthritis does not approach its maximum until the patients have attained the mean age of 60–65 at follow up 20 years later At follow up at a mean age of 70–75 years the percentage of osteoarthritis has increased only slightly from the age of 60–65

In other words The follow up examinations by the various authors have disclosed

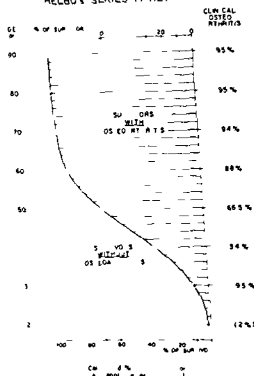


Diagram 25 Development of clinical osteoarthritis (pts. applying for treatm) in Helbo s series, calculated by using figures from Ruelle s total material (I + II) the maximum possible osteoarthritis rate in the series being fixed at 93 %

The percentages signify % osteoarthritis among survivors at the ages stated

These values do not correspond quite to those in Table 16 as the osteoarthritis rates on this diagram are birth date values i.e. the osteoarthritis rate when the patients pass the stated birthdays whereas the values in the table are the osteoarthritis rate when the mean age in the series is as stated

Calculation of the birth date values affords a possibility of a combination with the mortality curve as visualized in Diagram 6

Table 16 Calculated development of clinical osteoarthritis presented for treatment from 1930 to 1980 in the series followed up by Helbo and the percentage found at Helbo s follow up examination in 1950

Presented for treatm Osteoarthritis in patients who have applied for physiotherapy orthopaedic treatment radiotherapy or the like

The calculations were done using values from Ruelle s total material (I + II) Starting from the number and age distribution of the patients seen at follow up in 1950 they were carried out at 10-year intervals before and after the follow up examination

The calculated percentages are equal to the osteoarthritis rate in patients surviving at the times stated (cf Appendix Comment 5)

The maximum possible osteoarthritis rate in the series is fixed at 95 % (Appendix Comment 5)

Mean age	Calendar year	Clinical osteoarthritis in Helbo s series (I-HE)			
		Found	Calculated	Found	Found
		All cases of clinical osteoarthritis	Presented for treatment	Presented for treatment	Disabling osteoarthritis
		%	%	%	%
72 years	1980		93		
62	1970		85		
52	1960		67		
42	1950	62	41	34	21
32	1940		18		
22	1930		6		

Corresponding calculations may be carried out 20 years 30 years etc after follow up – and also 10 and 20 years before

The role of *normal mortality* in the older age groups may be taken into consideration – but it has proved of no major importance owing to the moderate age scatter in the materials

The result is given in Table 16 and Diagram 24

Diagram 24 Calculated development of clinical osteoarthritis (pts applying for treatm) in Helbo s follow up series (I-HE) performed by using figures from Ruelle s total material (I + II)

% = % of survivors at the times stated (with corresponding mean ages)

The % of osteoarthritis found at Helbo s follow up examination in 1950 is also listed (+ % radiol osteo arthr)

In other words the diagram is in all essentials a graphic presentation of Table 16 (cf legend of that table)

It will be seen that the % of clinical osteoarthritis (pts applying for treatm) calculated for 1950 – 41 % – is as expected somewhat higher than that found – 34 % (because the calculated percentage comprises a small number of patients who had not yet applied for treatment)

In exactly the same way the future development of osteoarthritis in Gower &

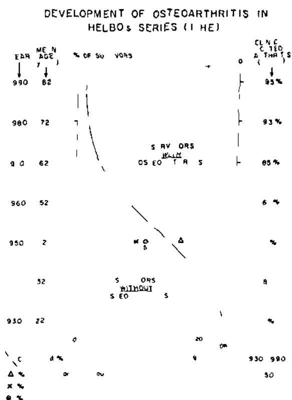


Table 17 Development of clinical osteoarthritis presented for treatment in the series followed up by Helbo Gower & Johnston and Danielsson & Hernborg calculated using figures from Ruelle s total material (I + II) based upon the age distribution at the time of follow up
% % of clinical osteoarthritis in the survivors at the time stated (Appendix Comment 5) Maximally possible osteoarthritis rates HE 95 %, GOW 86 %, DA 72 %.

	Calculated percentage of patients who have applied for treatment with symptoms of osteoarthritis					
	HE		GOW		DA	
	%	Mean age (years)	%	Mean age (years)	%	Mean age (years)
30 years later	93	72	85	75	69	71
20 years later	85	62	80	65	61	61
10 years later	67	52	65	55	46	51
At latest follow up examination	41	42	42	45	28	41

Johnston s and in Danielsson & Hernborg s series may be calculated

The total result of the calculations in all three series may be seen in Table 17

Thus if the follow up is repeated 10 years after that which has been performed – when the patients have attained a mean age of 50–55 years – the percentage of patients who had applied for treatment of osteoarthritis in Helbo s and in Gower & Johnston s series must be expected to have increased from about 40 % at a mean age of 40–45 years to about 65 % – or to almost two-thirds of the patients – in Danielsson & Hernborg s material presumably to one half

The development of osteoarthritis does not approach its maximum until the patients have attained the mean age of 60–65 at follow up 20 years later At follow up at a mean age of 70–75 years the percentage of osteoarthritis has increased only slightly from the age of 60–65

In other words The follow up examinations by the various authors have disclosed

DEVELOPMENT OF OSTEOARTHRITIS IN HELBO s SERIES (I HE)

Diagram 25 Development of clinical osteoarthritis (pts. applying for treatm) in Helbo s series calculated by using figures from Ruelle s total material (I + II) the maximum possible osteoarthritis rate in the series being fixed at 95 %.

The percentages signify % osteoarthritis among survivors at the ages stated

These values do not correspond quite to those in Table 16 as the osteoarthritis rates on this diagram are birth date values i.e. the osteoarthritis rate when the patients pass the stated birthdays whereas the values in the table are the osteoarthritis rate when the mean age in the series is as stated.

Calculation of the birth date values affords a possibility of a combination with the mortality curve as visualized in Diagram 26

only half the patients applying for treat ment of osteoarthritis *who will be found at* a follow up examination at a mean age of about 60

The calculated percentages express the number of cases of osteoarthritis in per cent of survivors (cf Appendix Comment 5)

If the number of cases of osteoarthritis in survivors is to be expressed as the percentage of the original number of pa tients in a series the mortality has to be

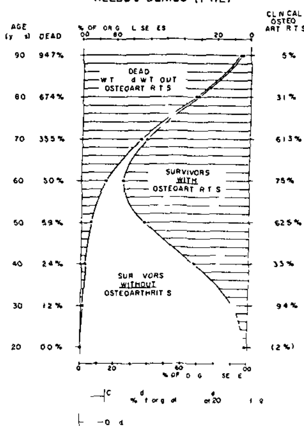


Diagram 26 Development of clinical osteoarthritis (pts applying for treatm) in Helbo s series calculated by using figures from Ruelle s total material (I + II) the maximum possible osteoarthritis rate being fixed at 95 %

The calculated osteoarthritis rates signify osteo arthritis in the survivors when they pass the birthdays stated expressed as % of the original series i e the number of patients at 20 years of age – not as in Diagram 25 as % of survivors

(Mortality curve in relation to 20 years of age Statistisk Årbog Denmark 1968 As to the use of Ruelle s figures cf Appendix Comment 5)

taken into consideration (cf Diagrams 25 and 26)

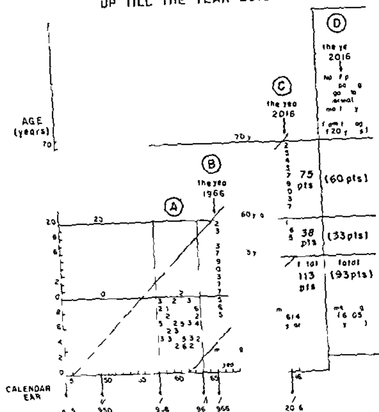
3 Calculated Clinical Long term Prognosis for the Three Series Not Yet Followed Beyond Primary Radiological Healing Wheelchair, Bed Rest and Traction Series

When the future rate of osteoarthritis in the LCPD series with late follow up can be calculated, it is of course also possible to calculate the subsequent development of osteoarthritis in the LCPD series treated in the 50's and 60's and only followed up to the time of primary healing – viz the wheelchair, bed rest and traction series

The only condition is to know – as in the series seen at follow up – the age distribution in one given calendar year after primary healing In the followed series this condition was fulfilled as the age distribu tion at follow up was known In the three *series not followed however the age distri* bution at a given time after primary healing may be determined on the basis of knowing the ages and the calendar year when the patients were started on treatment This is clearly apparent from Diagram 27 setting out the *traction* series The age distribution in this series can be found for any calendar year after 1963 (As already mentioned the normal mortality does not essentially alter the *age distribution* as the age disper sion is relatively slight)

Similar diagrams can be set up for the *bed rest* and *wheelchair* series

Incidentally the same method is ap plicable to Helbo s followed series in which patient age and calendar year at institution of treatment are known The development of osteoarthritis has been calculated on this basis – of course with practically *the same result* as when based upon age distribution at follow up Thus if Ruelle study had been known it *would have been possible already at primary healing in the 20 s to predict the development of osteoarthritis in the series so that follow-up more than 25*



D agra n 7 Age de el ›pment n the t action series up till the ye.r 016

A No of pts age ye at admiss on
B C Age d st b t on in the Tr se ies i 1966 and in 2016

On tl diagra n within the two diago tal li es – no regard is p d to normal mortality
Normal m rtality (Stat A bog 1968) educes the number of patients from 113 in 1966 to 109 in 1996 but the age di tr bution and thereby the o teoarthritis ate – is practically unaltered (1966 mortality not included osteoarthritis ate 8 4 in luded about 8 4) Up to the year 2016 the number of patients is reduced to 93 but the calculated o teoarthr tis rat is redu ed only from 9 5 to 29 4 (little age dispersion)

D Th special column g es the age dist ibution and the mean age in 01o paying regard to normal mortality since the ge J bout 0 }19 6)

years later would have confirmed what had been predicted

In the three more recent series the maximum possible osteoarthritis rate may be determined with far more accuracy than in the followed series as the size of the threatened groups PATH sph " + NON sph has been established by direct measurements (The percentages indicating the maximum possible rate of osteoarthritis will probably never come quite true unless some patients of the NORM sph group also develop osteoarthritis – which is of course not out of the question For further details concerning the max possible rate of osteoarthritis cf Appendix Comment 5

In the followed series figures from Ruelle s *total* material (I + II) were used for calculating the expected rates of osteoarthritis In the three more recent series treated far more energetically the joint

Table 18 Development of clinical osteoarthritis presented for treatment in the Wh BR and Tr series as referred calculated using figures from Ruelle s group II c

% = % of osteoarthritis in survivors at the mean ages stated

The maximally possible osteoarthritis rate was fixed at 53 % in the Wh series 54 % in the BR series and 35 % in the Tr series

Mean age	Expected rate of clinical osteoarthritis					
	Wh series (as referred)		BR series (as referred)		Tr series (as referred)	
(years)	%	Calendar year	%	Calendar year	%	Calendar year
71	51	2026	53	2019	34	2026
61	45	2018	46	2009	28	2016
51	30	2006	32	1999	20	2006
41	13	1996	14	1989	8	1996
36	6	1991	4	1984	4	1991
26	1 3	1981	0 7	1974	0 6	1981

deformities left by the disease are probably far less pronounced than in the poorly treated, followed series Therefore in calculating the *future* development of osteoarthritis in the wheelchair, bed rest and traction series, the author used figures from *Ruelle s mildest group* of osteoarthritis (II c) viz those following upon acetabular dysplasia (120 patients) instead of from his total material Possibly, the joint deformities in Ruelle s group II c were somewhat milder than in our three series Using the figures from Ruelle s total material we get somewhat higher osteoarthritis rates But the difference is not great Only the figures are shifted roughly 5 years downward in age – i e the osteoarthritis develops 5 years earlier – but otherwise according to the same pattern as when using the figures from Ruelle s group II c (Diagram 23)

Table 18 gives the result of the calculations based upon the values from Ruelle s group II c

The expected rates of osteoarthritis at a mean age of 40 are low 8–14 % Between 40 and 50 the percentages double and between 50 and 60 they rise by 50 % After the age of 60 the increase is slight

(The osteoarthritis rate may also be calculated in relation to the patients 40th 50th and 60th *birthday* instead of the *mean age* of 40 50 and 60 in the series This shows trebling of the osteoarthritis rate between the 40th and 50th birthday, as by this method we avoid the masking of the development of osteoarthritis caused by the use of the mean age The fact is that the osteoarthritis rates in the older and younger cases of the series alter less in the course of this decade than in the group around the mean age)

Of course the concrete figures in the table are fairly uncertain but the *relations* between the results obtained in the three series and the pattern of the development through the years are probably correct

Table 18 shows the clinical long term prognosis in the three *series as referred* calculated by the aid of Ruelle s values on the basis of the joint deformities present at primary healing

On the other hand it does not afford reliable information about the *relative* efficacy of the three therapeutic methods which is masked by the different severity of the series at referral

It is possible to throw light upon this aspect only by analysing the radiological and the consequent clinical results of the three methods in uniform parts of the three series – which affords small groups of patients – or in one series composed either as the wheelchair series the bed rest series or the traction series

In the radiological sections the author

arrived at the result that the latter method was more reliable Therefore the calculated radiological results of the three therapeutic methods in *one* series of *the same* composition *as the wheelchair series* – or more correctly in three identical series thus composed – were used for determining the efficacy of the three therapeutic methods with a view to late clinical results The result may be seen from Table 19

In this table the development of osteoarthritis is naturally according to the same pattern as in Table 18 The order of magnitude of the figures has also not changed but the picture of the relative efficacy of the three therapeutic methods is more distinct not masked by the difference in severity between the three treated series

It is apparent that in this table the rate of osteoarthritis after *bed rest treatment* and *traction treatment* is lower in relation to that after *wheelchair treatment* than it was in Table 18 – after traction treatment only half that after wheelchair treatment

This seems a striking difference – but if the results are expressed in the percentage of cases *without* osteoarthritis it is not quite so outstanding At the mean age of 41 years 87 % are without osteoarthritis after wheelchair treatment and 94 % after traction a fairly unimportant difference At this mean age all three forms of treatment have given good results The relation between the few poor results is not of major practical importance

The difference between the percentage of cases *without* osteoarthritis (after the three methods) does not really manifest itself until the mean age of 51 years 70 % 74 % and 86 % after wheelchair bed rest and traction respectively Thus after treatment by traction there are 23 % more cases without osteoarthritis than after treatment in wheelchair and at the mean age of 61 years 44 % more All this is clearly evident from Diagram 28 which affords a good survey of the expected late clinical results of the three methods of treatment

Using the figures from Ruelle s total material (I + II) gives a somewhat lower percentage of cases without osteoarthritis at the ages of 51 and 61 as the osteoarthritis develops 5 years earlier

However the use of Ruelle s mild group (II c) probably affords the more correct results

Then Table 19 and Diagram 28 afford *the final answer to the object of this study To establish the late clinical result of the three methods of treatment when applied under uniform conditions*

The *course of the study* which led to this result was First a description of the radio-

Table 19 Calculated *development of* *l nical osteoarthritis presented for treatment in a series composed like the Wh series treated by Wh or BR or Tr*

% ? of osteoarthritis in survivors at the mean ages stated

In the c lculation figu es from Ruelle s group II c were used

The maximally possible osteoarthritis rate was fixed at 53 ? after Wh treatment 46 ? after BR treatment and 25 ? after Tr treatment

Mean age	Calendar year	Expected rate of clinical osteoarthritis in a series composed like the Wh series treated by		
		Wh treatment	BR treatment	Tr treatment
(years)		%	%	ᶜʳ
71	0 6	51	45	24
61	016	45	39	21
51	.006	30	6	14
41	1996	13	11	6
36	1991	6	5	3
.6	1981	1 3	1	0 6

Table 18. [illegible] of clinical osteoarthritis presented for treatment in the Wh, BR and Tr series as referred [illegible] figures from Ruelle's group II c

[illegible] in our series at the mean ages stated

The [illegible] osteoarthritis rate was fixed at 53 % in the Wh series, 54 % in the BR series, and 35 % in the Tr series

Mean age (years)	Expected rate of clinical osteoarthritis: Wh series (as referred) %	Wh series (as referred): Calendar year	BR series (as referred): %	BR series (as referred): Calendar year	Tr series (as referred): %	Tr series (as referred): Calendar year
71	[illegible]1	202[illegible]	53	2019	34	[illegible]026
[illegible]1	45	2018	46	2009	28	[illegible]016
[illegible]1	30	2006	32	1999	20	2006
41	13	1[illegible]6	14	1989	8	1996
[illegible]	6	1[illegible]1	4	1984	4	1991
2[illegible]	1 3	1[illegible]81	0 7	1974	0 6	1981

deformities left by the disease are probably far less pronounced than in the poorly [illegible] followed series. Therefore, in calculating the *future* development of osteoarthritis in the wheelchair, bed rest, and traction series the author used figures from Ruelle's *mildest group* of osteoarthritis (II c, viz. those following upon acetabular dysplasia (120 patients) instead of from his total material. Possibly, the joint deformities in Ruelle's group II c were somewhat milder than in our three series. Using the figures from Ruelle's total material we get somewhat higher osteoarthritis rates. But the difference is not great. Only, the figures are shifted roughly 5 years downward in age, i.e. the osteoarthritis develops 5 years earlier, but otherwise according to the same pattern as when using the figures from Ruelle's group II c (Diagram 23).

Table 18 gives the result of the calculations based upon the values from Ruelle's group II c.

The expected rates of osteoarthritis at a mean age of 40 are low, 8–14 %. Between 40 and 50 the percentages double, and between 50 and 60 they rise by 50 %. After the age of 60 the increase is slight.

(The osteoarthritis rate may also be calculated in relation to the patients' 40th, 50th and 60th *birthday* instead of the *mean age* of 40, 50 and 60 in the series. This shows trebling of the osteoarthritis rate between the 40th and 50th birthday, as by this method we avoid the masking of the development of osteoarthritis caused by the use of the mean age. The fact is that the osteoarthritis rates in the older and younger cases of the series alter less in the course of this decade than in the group around the mean age.)

Of course the concrete figures in the table are fairly uncertain, but the *relations* between the results obtained in the three series and the pattern of the development through the years are probably correct.

Table 18 shows the clinical long term prognosis in the three *series as referred*, calculated by the aid of Ruelle's values on the basis of the joint deformities present at primary healing.

On the other hand, it does not afford reliable information about the *relative* efficacy of the three therapeutic methods, which is masked by the different severity of the series at referral.

It is possible to throw light upon this aspect only by analysing the radiological and the consequent clinical results of the three methods in uniform parts of the three series — which affords small groups of patients — or in one series composed either as the wheelchair series, the bed rest series or the traction series.

In the radiological sections the author

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Using the figures from Ruelle s total material (I + II) gives a somewhat lower percentage of cases without osteoarthritis at the ages of 51 and 61 as the osteo- arthritis develops 5 years earlier

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The *course of the study* which led to this result was First a description of the *radio-*

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% ~ of osteoarthritis in survi ors at the mean ages stated

I the calculation figu es from Ruelle s group II c were used

The maximally possible osteoarthritis ate was fixed at 53 ~ after Wh treatment 46 ~ after BR treatment and 25 ~ after Tr treatment

Mean age	Calendar year	Expected rate of clinical osteoarthritis in a series composed like the Wh series treated by		
		Wh treatment	BR treatment	Tr treatment
(years)		%	%	%
71	026	51	45	24
61	016	45	39	21
51	006	30	26	14
41	1996	13	11	6
36	1991	6	5	3
46	1981	1 3	1	0 6

Table 18 Development of clinical osteoarthritis presented for treatment in the Wh BR and Tr series as referred calculated *using figures from Ruelle s group II c*
% = % of osteoarthritis in survivors at the mean ages stated
The maximally possible osteoarthritis rate was fixed at 53 % in the Wh series 54 % in the BR series and 35 % in the Tr series

Mean age	Expected rate of clinical osteoarthritis					
	Wh series (as referred)		BR series (as referred)		Tr series (as referred)	
(years)	%	Calendar year	%	Calendar year	%	Calendar year
71	51	2026	53	2019	34	026
61	45	2018	46	2009	28	2016
51	30	2006	32	1999	20	2006
41	13	1996	14	1989	8	1996
36	6	1991	4	1984	4	1991
26	1 3	1981	0 7	1974	0 6	1981

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The expected rates of osteoarthritis at a mean age of 40 are low 8–14 % Between 40 and 50 the percentages double and between 50 and 60 they rise by 50 % After the age of 60 the increase is slight

(The osteoarthritis rate may also be calculated in relation to the patients 40th 50th and 60th *birthday* instead of the *mean age* of 40 50 and 60 *in the series* This shows trebling of the osteoarthritis rate between the 40th and 50th birthday as by this method we avoid the masking of the development of osteoarthritis caused by the use of the mean age The fact is that the osteoarthritis rates in the older and younger cases of the series alter less in the course of this decade than in the group around the mean age)

Of course the concrete figures in the table are fairly uncertain but the *relations* between the results obtained in the three series and the pattern of the development through the years are probably correct

Table 18 shows the clinical long term prognosis in the three *series as referred* calculated by the aid of Ruelle s values on *the basis of the joint deformities* present at primary healing

On the other hand it does not afford reliable information about the *relative* efficacy of the three therapeutic methods which is masked by the different severity of the series at referral

It is possible to throw light upon this aspect only by analysing the radiological and the consequent clinical results of the three methods in uniform parts of the three series – which affords small groups of patients – or in one series composed either as the wheelchair series the bed rest series *or the traction series*

In the radiological sections the author

exact figures (31 % 47 % etc) This numerical accuracy does not reflect the real uncertainty – which is appreciable

The sources of error are numerous and it is difficult to assess their role

The calculations are based upon different figures *Measurements* on X ray films of varying accuracy *figures* from reports in the literature often of regrettable brevity and questionable relevance

Lastly the correctness of the calculation depends entirely upon whether these uncertain figures are interpreted and used in the right way

En route to these final tables – and others similar to it in the clinical section – there are in short so many factors of uncertainty and so many pitfalls that it may be asked whether the efforts were worth while

To this scepticism it may be rejoined that at present at least there is no other possibility of elucidating these problems

Moreover the uncertainty is hardly so great that the results can be dismissed as being of no major interest

True the concrete figures should no doubt be regarded with a great deal of reserve However the *relations* between the tabulated figures vertical as well as horizontal are based upon so much consistent evidence obtained by different methods of measurement and calculation that in broad features they will probably prove to correspond to the actual findings at the time when sufficiently late follow up studies can be performed – i e when the mean age is at least 60 years

In the case of our three series this will not be until the years 2009–2016

POSTSCRIPT 1974 TO CLINICAL SECTION

Attempt at Checking the Calculated Late Development of Osteoarthritis in HELBO s *Series*

A Follow-up After a Minimum of 50 Years

After completing the work described above the present author in collaboration with Mose et al – conducted a follow up examination in 1974 of those who could be traced of Helbo s patients who had attended follow up already in 1950 Regrettably it was possible to trace only 25 of the 36 who are presumed to be still alive From a statistical point of view therefore the results are very uncertain

In 1974 all 25 patients had been followed for more than 50 years – *mean* follow up period 57 years Their mean age was 65 approximately the same mean age and age distribution that might be expected if all survivors had been traced

A detailed account of the total result will be published later by Mose et al Here follows merely a brief report of that part of the results which bears relation to the problems of the present study

It must be pointed out first that what characterizes Ruelle s patients is that sooner or later all *applied for institutional treatment* of their arthritic symptoms No mention is made of any *other characteristic* of their osteoarthritis

Therefore if the osteoarthritis rates *calculated* on the basis of *Ruelle* s figures are to be *compared with* those actually found they have to be compared with the percentage of patients found who had applied for treatment of their osteoarthritis (Appendix Comment 5)

However Ruelle s figures comprise also a small number of patients who had not yet *applied* for treatment at the ages stated – though decreasing as time went by (Appen

CALCULATED DEVELOPMENT OF OSTEOARTHRITIS IN THE Wh SERIES AT 3 DIFFERENT METHODS OF TREATMENT

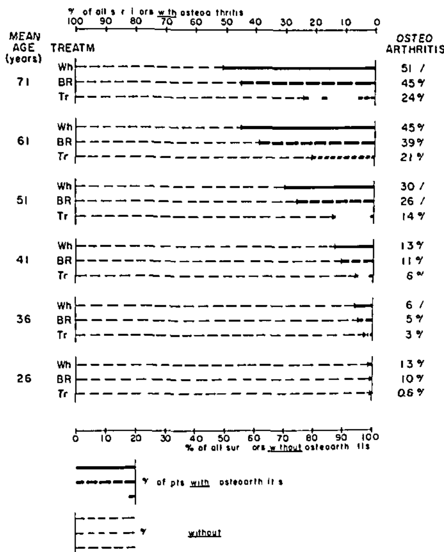


Diagram 28 Expected (calculated) clinical osteoarthritis (pts applying for treatm) in a series composed like the Wh series (with regard to age and stage at institution of treatment) after 3 different methods of treatment (Wh BR and Tr)

% of survivors calculated by using figures from Ruelle s group II c

The series are arranged according to – –→ + osteoarthritis from L to R

logical results obtained by the three methods – paying particular regard to the fact that the methods had been applied to series of different severity

Thereafter a review of the available *follow-up reports of LCPD series* This afforded a picture of the actual development of radiological and clinical osteoarthritis in more or less effectively treated series up to the mean age of approx 40

Finally studies of special *series of osteoarthritis* (int al Ruelle s) supplied information as to how symptoms of secondary osteoarthritis developed up to an advanced age after different degrees of articular deformity

By a combination of these three groups of data – *radiological and clinical* the author arrived at the figures set out in Tables 18 and 19

The figures in these tables were obtained by calculation – and they are stated in

be demanded I therefore ventured to use Ruelle's figures for calculating the size of the group of patients who had applied for treatment up to an advanced age

According to Table 16 this group would *be expected to make up* 85 % of all survivors in 1970 20 years after the follow up examination and in 1974 90 %. If the relation of this calculated percentage to the percentage of patients who had applied for treatment actually found was the same in 1974 and in 1950 75 % of the survivors would be expected to have applied for treatment of osteoarthritis in 1974

But as already mentioned it must be anticipated that the older the patients get the higher a percentage of the calculated number – and incidentally of all patients with radiological osteoarthritis – will have applied for treatment of their symptoms In other words it must be expected that the number of patients with osteoarthritis who had applied for treatment will approach the calculated rate with advancing age – and that in 1974 it ought to be somewhere between 75 % and 90 % of the surviving patients

The actual finding was 84 per cent

Thus the rate was 93 % of the calculated rate as compared with only 83 % in 1950

It may be added that the majority of the 84 % patients who had applied for *treatment of* osteoarthritis were also more or *less disabled* (76 % of the total patients)

Diagram 29 clearly sets out the relations between the calculated and found values – *in 1950* and *in 1974* (cf also the legend)

However the values listed in the diagram require a comment

All the percentages *found* and *calculated* in 1974 are *maximum values*

Of the cases of *radiological* osteoarthritis found 2 or 3 must be said to be questionable even to experienced radiologists (Helbo's Cases 58 112 and 119) They are included as radiological osteoarthritis because *the presence* of radiological osteoarthritis cannot be excluded

The number of patients found with *clinical* osteoarthritis (21) is also at the upper limit

It is common to them all that at some time or other they had applied for *treatment of their symptoms* In other respects they fall into several groups

The largest group (12/21) had symptoms and signs of *osteoarthritis of the hip* only – and no complicating features All could indubitably be called cases of secondary osteoarthritis of the hip

But a smaller – but nevertheless a surprisingly large – group (9/21) had in addition to symptoms and signs of osteoarthritis of the hip also low back pain lumbago stiffness of the back with limitation of movement radiating pain in the legs etc

Some had only backache *without* objective signs of vertebral disease – evidently merely pain radiating from the hip disease – but the majority had *radiological changes of the spine* indicating that in fact the back complaints originated from the spine There might be merely static changes in the shape of the spine scoliosis lordosis etc or signs of actual diseases Spondylarthritis degeneration of intervertebral discs spondylolisthesis etc

In these cases the back complaints usually appeared later than occasionally at the same time as – the symptoms of osteoarthritis of the hip When also considering the striking frequency of back *complaints* in the material this rendered it likely that an essential proportion of the vertebral lesions had developed *secondarily to the* osteoarthritis of the hip *possibly to the* primary LCPD

In cases where the back complaints were *merely a superstructure* on well-defined osteoarthritis symptoms from the hip (5 *patients) they* could rightly be assigned to *the group* osteoarthritis of the hip The back complaints – and the underlying vertebral lesions – *were in fact merely* a further development of *pure secondary* osteoarthritis of the hip *Yet it must* be

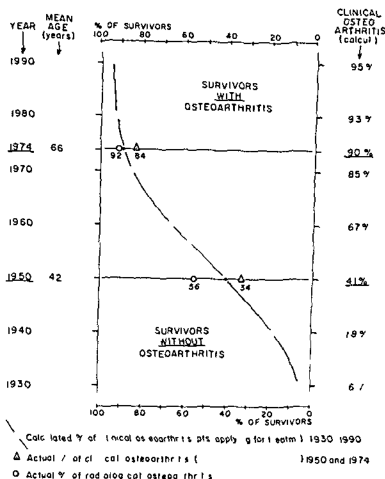


Diagram 29 Calculated *development of clinical osteoarthritis (pts applying for treatm) in Helbo s series (1–IIE) performed by using figures from Ruelle s total material (I + II)*

% = % of survivors

The diagram also lists the osteoarthritis rates found *at Helbo s follow up examination in 1950 and at the follow up examination in 1974*

It will be seen that the clinical osteoarthritis rates calculated for 1950 and 1974 (pts applying for treatm) 41 % and 90 % are – as might be expected – somewhat higher than those found (34 % and 84 %) because the calcul ted rates comprise a small number of patients who have not yet applied for treatment

Comment Diagram 29 is not quite correct The curve was traced on the presupposition that the follow up examination in 1974 comprised all survivors from Helbo s 1950 follow up examination but it comprises only part of them (25/36 pts) However if the calculation for 1974 is performed with the correct mean age and age distribution the result will be only a trifle lower than the figures on the curve (88 5 %/90)

Thus it seems permissible to trace the curve together with the results of both follow up examinations

This renders the diagram more instructive

dix Comment 5) Thus osteoarthritis rates calculated on the basis of Ruelle s figures must be expected to be somewhat higher than the percentages of patients who had applied for treatment found at follow up

From Table 14 it is apparent that at follow up in 1950–1951 Helbo found signs of *radiological* osteoarthritis in 56 % of the patients and that 34 % had applied for treatment because of its symptoms

Calculation using Ruelle s figures re sulted in 41 % who had applied for treat ment of osteoarthritis – indeed as ex pected a somewhat higher rate than that actually found

This was an agreement as close as could

be said to constitute a risk to LCPD patients

Let it be added that these cases of mild but typical LCPD had healed with *spherical heads* In other words they afford examples that healing with spherical heads is no guarantee against the development of radiological osteoarthritis of the hip and late hip-back symptoms

Yet another case (HE No 85) had healed with a spherical head In this case there were no radiological signs of osteoarthritis and the patient was symptom free

From this review it is apparent that the great majority of these cases of secondary osteoarthritis of the hip hip back syndrome and late symdromes in general may *be collected under the designation secondary osteoarthritis of the hip in an extended sense* as described above

The few cases – at an estimate two or three – in which there could be some doubt were nevertheless assigned to this group This means of course that the percentage of patients with clinical osteoarthritis *found* in *1974* and depicted in Diagram 29 must be regarded as a maximum percentage – just like that of patients with radiological osteoarthritis

The *calculated* percentage of patients with clinical osteoarthritis is also a *maximum value*

All calculations are based upon the radiologically estimated maximum possible percentage of osteoarthritis in the material = 95 % i e the *radiological groups* NON sph and PATH sph combined It was found however that this percentage had to be reduced at least somewhat – probably to about 90 % as 4 6 per cent of the *potential cases* of osteoarthritis will die before they develop osteoarthritis In addition a few of the numerous potential osteoarthritics will indubitably *not develop* the expected osteoarthritis even though they live to a ripe old age When considering the relation of the *calculated* percentage to that *found* at Helbo s follow up study *in 1950* – whose correctness we are unable to check and therefore *must accept* – such further reduction *cannot however* exceed about 5 % (to approx 85 %) – at least not if figures from Ruelle s total *material* (RU I + II) *are to be used in the* calculation (If the reduction is to be greater figures from one of Ruelle s smaller groups *have to be used in the* calculations (e g RU I))

It must be pointed out that a possible *reduction in the final maximum* osteoarthritis rate cannot alter the fact that all patients in 95 % of the material – i e in the patient groups NON-sph and PATH sph – are at risk since the reduced final percentage of cases of osteoarthritis will spread over 95 % of the material

However it is extremely difficult to fix the correct magnitude of such a reduction Therefore the more accurately defined 95 % will be maintained as a basis for the calculations

This makes the rate of clinical osteoarthritis in Helbo s *material calculated for* 1974 also a *maximum percentage* – like the radiological and clinical rates of osteoarthritis actually *found*

Of course the *calculated* and the *two found* maximum values may be reduced (by approx 8–12 % for all three rates) to values which are perhaps more realistic but the reduced values will presumably prove even more uncertain than the maximum ones

And this does not essentially alter the relation between the rates

After these comments the result of the follow up study may be briefly worded as follows

92 % of the patients *exhibited definite* – or possible – signs of radiological osteoarthritis

84 % had applied for treatment of secondary sequelae to LCPD – as a rule secondary *osteoarthritis of the hip* A number of

conceded that in these cases the term osteoarthritis of the hip embraces a more comprehensive syndrome than indicated by the name A more apt term might be *secondary hip-back syndrome* perhaps only "late secondary syndrome It is indeed by no means certain that the late sequelae to LCPD are restricted to these two skeletal sites

In a small number of patients (4) the radiological signs of osteoarthritis in the hip were not marked, but indubitable, and the hip symptoms were so mild that the *back complaints were predominant* In such cases it was more doubtful whether the term osteoarthritis of the hip was justified

However, in a couple of these patients the back complaints were evidently due essentially to static abnormality of the spine, caused by the *primary hip deformity* following upon LCPD However, the temporal occurrence – and exacerbation – of the back symptoms does not seem unrelated to the development of the mild *osteoarthritis* of the hip *Therefore these hip back syndromes might also be interpreted as secondary osteoarthritis of the hip* in an extended sense At least they were secondary to LCPD

In the *remaining two patients* with mild symptoms and signs of osteoarthritis the relation of the vertebral disease to that of the hip – the primary LCPD or the osteoarthritis – was more questionable There might be a chance coincidence of hip and back disease but a relation to the hip disease could not be excluded in either case

Experience has shown that LCPD is not merely a local hip disease but is associated with a generally altered state of the entire skeleton – manifesting itself int al in delayed development of the ossification centres in the carpus reduced longitudinal growth and the not uncommon occurrence of aseptic necroses in other epiphyses – multiple aseptic epiphyseal necroses

Apart from this LCPD or LCPD like radiological changes are not uncommonly encountered as part of certain, familial 'enchondral dysostoses' (Mau 1958), in particular dysplasia epiphysialis multiplex and Morquio's symdrome (Rubin, Fairbank) *In mild and early cases of these two syndromes the differential diagnosis against pure LCPD may even be difficult* (Fairbank 1951)

Morquio s syndrome usually involves considerable deformities of the vertebrae – dysplasia epiphysialis multiplex more rarely The question now arises whether some of our combined hip back syndromes might be examples of such combined *skeletal diseases* on a constitutional basis, especially the cases in which the back disease was not likely to be secondary to the hip disease

In *one of these cases* (Helbo s Case 1) the hip disease was combined with a congenital spinal defect and an atypical disease of the central nervous system (CNS) 'presumably disseminated sclerosis

With regard to the latter complication, it is enlightening that five familial cases of such combined disease of the hip pelvis, spine and CNS have been reported by Jequier and Streiff (1947) In their opinion the disease of the hip represented the sequelae to *LCPD the diseases* of the CNS had features of congenital spastic paraplegia as well as of disseminated sclerosis

The other case (Helbo s Case 107) is spondylolisthesis of the type which is familial (Newmann 1963) Newmann feels that the cause of this type is most probably stress fracture arising in constitutionally weakened bony tissue (+ ligaments)

In both cases the symptoms were of late onset

These two cases might be interpreted as combined hip back diseases on a constitutional basis – and the possibility that such cases *may* develop in a LCPD material *must*

CONCLUDING REMARKS

1 Out patient and In patient Treatment

The main result of the present study is that in patient treatment with traction affords better results than bed rest in hospital without traction and out patient treatment in wheelchair This is apparent from the X ray films already at primary healing – but does not manifest itself clinically until an age of almost 50

Thus the choice between in patient treatment with and without traction is not difficult

It is a different matter when choosing between in patient treatment with traction and out patient treatment in wheelchair During the 1950 s and 1960 s there have been constant paediatric warnings against treating children in hospital It is claimed that a stay in hospital is a greater strain and psychlologically far more harmful than treatment carried out at home The most convinced adherents of these views are even prepared to accept an essentially poorer somatic result if only the treatment takes place at home

Therefore before choosing between in patient and out patient treatment one must make up one s mind about these still widely held views on the harmful effect of hospital treatment upon children

Are they based on realities?

To me it is doubtful

At the Seaside Hospital Refsnæs about 500 children with LCPD have been treated Of them I have seen 300–400

Children with LCPD are put into 4–8 bed wards and all are so to speak in the same boat where nobody can feel odd man out in the environment They are surrounded by an experienced and large staff of doctors nurses nurses aides occupational therapists, and teachers to look after their correct treatment entertainment occupation and instruction

Nothing amuses children more than being with other children in the same situation and of the same age Throughout the day this companionship – indoors and out of doors – is full of diversions and fun The result has been largely a collection of happy and well adapted children with whom it has been a daily encouragement to associate

I have followed all the children until they were 16–18 years of age and neither their parents nor I have found that they differed in any way mentally from a corresponding group of children and adolescents who have never been ill

On this background I try to visualize out patient treatment with crutches or wheelchair at home – possibly in a flat – among healthy sisters brothers and mates under the responsibility of anxious parents I must confess that I have some difficulty

these elderly *patients* however, had devel oped a hip back syndrome in a few of them even with predominance of the back complaints

Nevertheless all could be assigned to the group with secondary osteoarthritis of the hip on the grounds stated above

The main object of the follow up study was to check the calculated percentage of patients who had applied for treatment of secondary osteoarthritis up to 1974

According to the calculation 90 % of the patients would be expected to belong to this group At follow up the rate was found to be 84 %

As it had been anticipated that the calculated rate was somewhat higher than that found, it must be concluded that the pre calculated percentage afforded reasona bly good guidance concerning the percen tage that would be found in 1974

Diagram 29 then affords a perspicuous survey of the agreement between the calculated and found rates of osteoarthritis in Helbo s material at the follow up studies in 1950 and in 1974

Despite all uncertainty, such an agree ment ascertained at repeated late follow up studies of Helbo's patients – most recently with a follow up period exceeding 50 years – must strengthen confidence in the cal culations performed to predict the develop ment of osteoarthritis in the three more recent series treated *by wheelchair bed rest without traction* and *bed rest with trac tion*

However as already mentioned the cor rectness of these predictions cannot be checked until at follow up of the patients after the year of 2000

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in convincing myself that treatment at home is on the whole less of a strain on the children than treatment in hospital

On the basis of my, somewhat one sided experience I can only say with certainty The majority of the children adjust surprisingly well to hospital life This may seem surprising but it remains a fact The explanation is probably that children have an amazing ability to put up with and remain unaffected even by the most peculiar circumstances

To me therefore it is difficult to perceive the harmful effect of hospital treatment upon children – on the understanding that it takes place in a well suited institution As the somatic results of traction in hospital are – according to what has been stated above – definitely superior to those of out patient treatment in wheel chair I find no difficulty in concluding that

Children with LCPD should as far as possible be treated by traction in hospital

But of course it must be admitted that this is not always possible

In the first place a small number of children cannot put up with treatment in hospital and a small number of parents cannot do without their children at home Under such circumstances it should naturally be endeavoured to carry out home treatment as effectively as possible

In the second place a suited institution is not at disposal everywhere This is probably the most common motivation for choosing out patient treatment

From my 1966 publication the present study and Jorgen Lauritzen s it is apparent that out patient treatment in wheelchair is considerably more effective than out patient treatment with a Thomas caliper It has the great advantage among others that it permits non weightbearing in *both* hips Therefore bilateral cases can also be treated – and in unilateral cases the very regrettable secondary development of LCPD in the good hip is avoided

I doubt that a more effective out patient treatment is available

2 Radiological and Clinical Evaluation by Two Examiners

The radiological evaluations in the present study are of little value, if the measurements on which they are based cannot be reproduced with approximately the same result by others without a knowledge of J M s measuring results

Therefore, as already mentioned the X ray films of all patients in the three series were measured not only by J M but also independently, by Lauritzen (LAU) who reported his results in 1975 (Diss)

A total of about 4000 measurements were performed by both examiners – plus reading of 112 films showing non spherical heads – for which the only measurement needed was ascertaining the absence of a spherical shape by means of Mose s plate

In a large number of cases the examiners measured on the same film but owing to the shift in the time of measurement in several cases on different films of the same patient I even did an extra series of measurements in the traction series to adapt the observation periods to LAU s

Therefore direct comparison of the measurements for each individual patient is of less interest – but can be done by comparing J M s and LAU s patient lists The patients of the traction and bed rest series have identical numbers in both publications A list of the corresponding numbers in the wheelchair series may be seen in the Appendix before the patient lists

What is of interest is the comparison of the two sets of evaluation *results* obtained by the use of the independent measurements by the two examiners in particular to ascertain whether agreement exists between the results affording the most reliable picture of the relative efficacy of the three methods of treatment The results in the same series or in 3 identical series

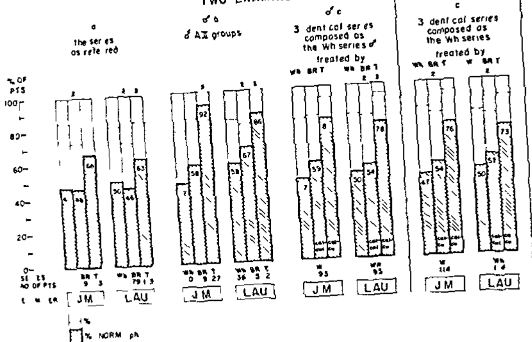


Diagram 30 Rad ological results of treating the listed series and groups of patients by Wh BR and Tr based upon measurements on X ray films performed by 2 examiners independently of each other

The columns show the result of treating

			JM[1])	LAU[2])
a	1 the Wh series as referred by Wh	(SPH	85 7	8? 7)
	2 the BR series s referred by BR	(	73 "	72 ")
	3 the Tr series as referred by Tr	(	84 "	84 ")
δb	1 the δA II group of the Wh series by Wh	(SPH	77 %	83 ")
	2 the δA II group of the BR series by BR	(	84 7	80 ")
	3 the δA II group of the Tr series by Tr	(	100 7	100 7)
δc	1 the δ of the Wh series as referred by Wh	(SPH	82 %	83 ")
	2 the δ of the Wh series as referred by BR (cal)	(	83 "	82 7)
	3 the δ of the Wh series as referred by Tr (cal.)	("	93 7	94 %)
c	1 the Wh series as referred by Wh	(SPH	85 "	82 7)
	2 the Wh series as referred by BR (cal.)	(	82 %	80 7)
	3 the Wh series as eferred by Tr (cal)	(	91 7	90 7)

A tot l survey of the rad ological results (JM) is given in the Appendix Table 27

The 3 groups of pat ents designated δb are the prognostically most un form ones that can be singled out of the series but the res lts in group c are prob bly of most practical inte est

[1]) JM % calc lated us ng JM s measurements by JM   [2]) LAU % calculated using LAU s measurements by JM

(Abbr iatu ns and symbols p 1)

which may be calculated from Lauritzen as well as from my figures

As a main example Diagram 30 (c) shows the results of the 3 therapeutic methods in a series composed like the wheelchair series as these results have some practical perspective (Of course series composed like the traction or bed rest series would

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scribed the efficacy of his treatment with that of wheelchair bed rest and traction treatment as described in the present study

Such a possibility of comparison must facilitate the efforts at arriving at thera peutic methods affording an even better radiological result

Similar agreement between two ex aminers can be obtained also by means of simpler methods of evaluation the one quotient methods mentioned above

Diagram 31 is an example (cf also Appendix Comment 2)

But the *radiological* result is not the essential thing only a basis for the evalua tion of the *final clinical result* which is decisive The agreement between LAU and J M comes to an end at least partially in predicting the clinical consequences of the radiological results i e in deciding which radiological group of patients will presuma bly not develop secondary osteoarthritis even at an advanced age and which groups are at risk

My investigations led to the conclusion that only patients in the radiological group called NORM sph (= LAU s excellent) obtained a radiological result preventing in all essentials the development of secondary osteoarthritis LAU on the other hand feels that all patients of the spherical group (= J M SPH) will remain free of osteoarthritis (LAU Thesis 1975 p 36)

LAU as well as J M have based their conclusions concerning the clinical implica tions of the radiological result mainly on the review of a number of reports in the literature on follow up of patients with a history of LCPD during childhood – but they have not arrived at the same result

In a detailed review of 19 reports on follow up studies (described in the present publication pp 39–52) on which I based my conclusion it was evident that several difficulties were involved in drawing a conclusion regarding the relation of the *primary radiological result* to *subsequent development of osteoarthritis* These dif ficulties have not quite manifested them selves in LAU s review of the literature used by him But of course they are present also in these reports all the more so as they are largely the same as those reviewed by J M

First the majority of the follow up studies on which LAU based his conclusion were carried out at too early an age – in the early or middle twenties As secondary osteoarthritis usually does not properly start until the forties it is not surprising that LAU found osteoarthritis only in cases with the most severe deformities The latest follow up studies were in fact also too early – the mean age being only about 40

Secondly spherical and round in the literature usually means golf ball shaped or more correctly 3/4 golf ball shaped i e exactly NORM sph – in LAU s terminology excellent – and cer tainly not spherical as defined by Mose and used by LAU himself – and J M – to characterize the cases in the spherical group – J M s SPH

The group spherical (SPH) in LAU s J M s and Mose s sense is a *far more comprehensive* group than the spherical in the literature comprising several appreciably deformed cases cases with mushroom-shaped heads but with a circular outline as defined by Mose (cf Fig 1 a and b)

Therefore although the spherical group from the literature seems to avoid osteoarthritis LAU cannot draw the con clusion that *his* spherical group will avoid it As substantiated by the present author the conclusion that can be drawn from the literature is that only patients of the group NORM sph (excellent) re main free of osteoarthritis

But when LAU applied *his* criterion – that all patients of the spherical group remain free of osteoarthritis – to evalua ting the efficacy of the various therapeutic methods he arrived in fact at the same *main* conclusion (LAU Thesis 1975 pp

2 EXAMINERS
I QUOTIENT ASSESSMENT USING THE RADIUS QUOTIENT

c c

the Wh series treated by

Diagram 31 Radiological results when treating the Wh series as referred by Wh BR or Tr (the results of BR and Tr calculated)

The assessment was exclusively by the aid of the radius quotient *(I quotient assessment) measured by 2* examiners *independently of each other*

Radiological result of treating

		JM[1])	LAU[2])
c	*1 The Wh series as referred by Wh (SPH*	*85*	*82 %)*
	2 The Wh series as referred by BR (	*82 %*	*80 %)*
	3 The Wh series as referred by Tr (	*91 %*	*90 %)*

[1])*JM % calculated using JM s measurements by JM*

[2])*LAU % calculated using LAU s measurements by JM*

(% NORM sph Ra cf p 20 Other abbreviations and symbols on p 12)

have served just as well) As a supplement the two examiners results in other series and groups of patients are shown (a ♂ b ♂ c) Particular interest perhaps attaches to the direct results in the three series as referred (a)

According to the diagrams the agreement between the two examiners results in all series and groups of patients is in fact amazing In the main example (a) the percentages of NORM sph differ by at most 3 % and of SPH by at most 5 % (of all patients)

In other words two examiners working independently can perform the numerous measurements with such a degree of agreement that they arrive at practically the same evaluation of the efficacy of the three therapeutic methods

In consequence any clinician treating LCPD has a possibility of comparing by the use of the measuring methods de

Thus LAU s optimistic evaluation of the clinical sequelae in group SPH leads to an underestimate of the difference between the efficacy of traction and wheelchair treatment – and thereby to recommendations for treatment differing from those in the present *publication LAU states for* instance in his thesis p 129 that it is relatively immaterial how the patients of the oldest and youngest age group are treated the results of traction not being essentially superior to those of wheelchair treatment In only one special group of *patients in the middle age group does* LAU feel that traction is a definite advantage

The use of J M s criterion of a good result – % NORM sph – gives the results in the age/stage groups as shown in Diagram 4 (J M s measurements) In all ag /stage groups there is an appreciable difference *in the results between wheel* chair and traction treatment This difference is moreover accentuated in the oldest and especially the youngest age group when using LAU s own measurements (Diagram 3?)

The conclusion drawn from these results must be that as a general rule all age groups – also the oldest and youngest – should be treated by traction (Of course individual contra indications may exist)

In brief The two examiners LAU and J M measured the X ray films with identical *results* – but evaluated the clinical consequences of the radiological results differently

However it must be emphasized that according to its wording LAU s *main conclusion* that traction gives the best primary radiological results and thereby the *most favourable late clinical results is in* accurate agreement with J M s evaluation

The disagreement concerns only *how much better* the results are after traction

J M of course feels that the predictions concerning the late clinical results of the *three methods of treatment found in the* present study have better foundations and therefore will come true But the final decision must await the very late follow up examinations – and even from such examinations it is empirically difficult to form a definite opinion cf Postscript p 71

Table 20 Radiological results of wheelchair and traction treatments in the ♂A II groups of the series assessed by % SPH and by % excellent (LAU) (NORM sph J M) calculated on the basis of Lauritzen s as well as of J M s measurements

The ♂A II group of the Wh series includes only patients whose treatment had been carried out according to Lauritzen perfectly or well In the Tr series the ♂A II groups include only patients whose Tr treatment has been carried through for 12 months or longer

		% SPH	No of pts.	% Excellent [1] equal to % NORM sph [2]	No of pts
LAU s measurements	Wh treatment of the ♂A II group of the Wh series carried out perfectly or well	88 %	(28/32)	58 %	(21/36)
	Tr treatment of the ♂A II group of the Tr series carried out ≥12 mo	100 %	(17/17)	89 %	(16/18)
J M s measurements	Wh treatment of the ♂A II group of the Wh series carried out perfectly or well	80 %	(28/35)	49 %	(17/35)
	Tr treatment of the ♂A II group of the Tr series carried out ≥12 mo	100 %	(25/25)	92 %	(23/25)

[1] (LAU) [2] (J M)

128–129) as I did on the basis of my conclusion

The result of traction is better than that of the other two methods of treatment

On the other hand, there is not agreement as to *how much better*

By the use of J M s criterion it will be found for instance, that *traction* treatment of a series composed like the wheelchair series gives a satisfactory result in about 60 % more patients than does *wheelchair* treatment (with traction 76 % NORM sph with wheelchair treatment 47 % NORM sph) – according to LAU s criterion in about 7 % (with traction 91 % SPH with wheelchair treatment 85 %) This corresponds to LAU s evaluation that the result of traction is slightly better than that of wheelchair treatment)

As regards the corresponding differences in other groups of patients using LAU s as well as J M s measurements cf Diagram 30 a ♂ b ♂ c and Table 20

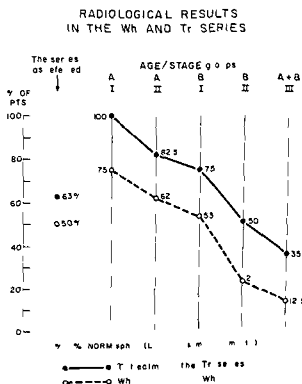


Diagram 32 Radiological results – only % NORM sph – in the Wh and Tr series as referred and in the age/stage groups of these series calculated using Lauritzen s radiological measurements

For comparison cf Diagram 4 The corresponding radiological results calculated using J M s radiological measurements

(Abbreviations and symbols cf survey p 1? No of pts cf Appendix Table 26)

Thus, LAU s optimistic evaluation of the clinical sequelae in group SPH leads to an underestimate of the difference between the efficacy of traction and wheelchair treatment – and thereby to recommendations for treatment differing from those in the present publication LAU states for instance in his thesis p 129 that it is relatively immaterial how the patients of the oldest and youngest age group are treated the results of traction not being essentially superior to those of wheelchair treatment In only one special group of patients in the middle age group does LAU feel that traction is a definite advantage

The use of J M s criterion of a good result – % NORM sph – gives the results in the age/stage groups as shown in Diagram 4 (J M s measurements) In all age/stage groups there is an appreciable difference in the results between wheel chair and traction treatment This difference is moreover accentuated in the oldest and especially the youngest age group when using LAU s own measurements (Diagram 3?)

The conclusion drawn from these results must be that as a general rule all age groups – also the oldest and youngest – should be treated by traction (Of course individual contra indications may exist)

In brief The two examiners LAU and J M measured the X ray films with identical results – but evaluated the clinical consequences of the radiological results differently

However it must be emphasized that according to its wording LAU s *main conclusion* that traction gives the best primary radiological results and thereby the most favourable late clinical results is in accurate agreement with J M s evaluation

The disagreement concerns only *how much better* the results are after traction

J M of course feels that the predictions concerning the late clinical results of the three methods of treatment found in the present study have better foundations and therefore will come true But the final decision must await the very late follow-up examinations – and even from such examinations it is empirically difficult to form a definite opinion cf Postscript p 71

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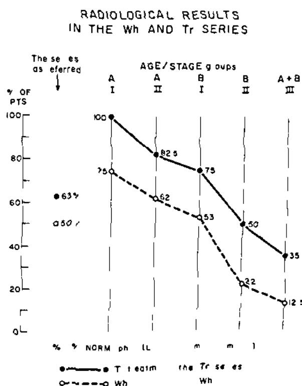


Diagram 32 Radiological results – only % NORM sph – in the Wh and Tr series as referred and in the age/stage groups of these series calculated using Lauritzen s radio*logical measurements*

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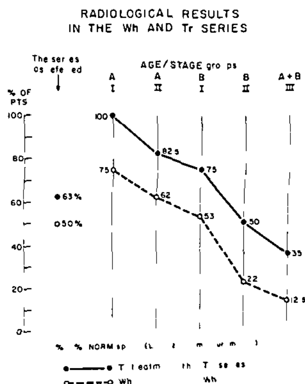


Diagram 32 Radiological results – only % NORM sph – in the Wh and Tr series as referred and in the age/st ge groups of these series calculated using Lauritzen s *radiological measurements*

For comparison cf Diagram 4 The corresponding radiological results calculated using J M s radiological measurements.

(Abbreviations and symbols cf survey p 12 No of pts cf Appendix Table 26)

Thus the larger this group in a treated series, the better the result

But now it was discovered that the three series differed mutually with regard to *factors* apart from the treatment *which affect the radiological result* In other words Differences in the radiological results between the three series reflected not only differences *in the efficacy of the* treatment but also differences in the nature of the series

Three factors were operative

1 The *stage of the disease* at the institution of treatment The earlier the stage the better the result
2. Patient *age* at institution of treatment The younger the better
3 *Sex* Boys attain – ceteris paribus – better results than girls

With regard to these three factors the wheelchair series proved to be more favourable than *the other two which did not* differ much mutually

With a view to eliminating the influence *of these three factors* the author picked out from each series a group – i e three in all – that was as far as possible uniform with respect to the named factors at the institution of the treatment (Designation ♂ A II – boys *of the middle age group* (II = 5–8 years) – who arrived for early treatment = A)

Now the radiological result in these *three groups of patients* ought to afford a reliable picture of the relative efficacy of the three therapeutic methods

Only there was a drawback of this *means of evaluation* viz that the number of patients in each group was regrettably small (40 20 and 27 pts)

However this drawback could be remedied

Each series was divided into six age/stage groups (disregarding the sex ratio which *was of minor importance)* in the way that the cases in identically designated groups of the three series must be presumed to have a uniform prognosis *prior to the institution* of treatment

Thereafter the efficacy of the three therapeutic methods in the these groups was analysed (Table 7 p 26)

By transferring for instance the percentage results in the groups of the traction *series to the corresponding* groups of the wheelchair series it was possible to ascertain which result would be obtained *by traction treatment of a series composed like the wheelchair series*

Table 1 Radiological results – % NORM sph – after 3 different methods of treatment (Wh BR and Tr)

A in three groups of patients having a uniform prognosis when referred (the ♂A II groups)

The differences between the results of Tr and Wh treatm. and between Tr and BR treatm in the groups are statistically significant (p <0 001 and p <0 02 respectively) (Cf also legend of Diagram 11 and survey in the Appendix Table 8)

B in a series composed like the Wh series.

Diagram 33 is a graphic presentation of this table

	Radiological results – % "NORM-sph." – of		
A	Wheelchair treatment in ♂A II group of the Wh series	Bed rest treatment in ♂A II group of the BR series	Traction treatment in ♂A II group of the Tr series
	47 %	58 %	92 %
B	Wheelchair treatment	Bed rest treatment in a total material composed like the wheelchair series	Traction treatment
	47 %	54 %	76 %

SUMMARY

An attempt was made to evaluate the efficacy of three non operative methods in the treatment of Legg Calve Perthes Disease (LCPD)

The criterion was the long term clinical result

The following methods had been applied

1 Out patient non weightbearing in a *wheelchair* – duration about 2 years
2 Non weightbearing in hospital by *bed rest without traction* for about 18 months followed by ambulatory non weightbearing for about 6 months – about 2 years in all
3 Non weightbearing in hospital by *bed rest with traction* for about one year followed by bed rest without traction for about 6 months and another 6 months of ambulatory non weight bearing – about 2 years in all

The starting point and the basis of the study were three different series (comprising 114 79 and 113 patients) each treated by one of the three methods

The late clinical result depends largely upon *the primary radiological result*

At first therefore the radiological result of each treatment was described by measurements on X ray films and assessed according to the radiological joint deformity left by the disease The less the deformit of the femoral head, the better the radic logical result Any joint deformities outsid the femoral head were interpreted as secor dary to the deformity of the head

The procedure of measurement in series was as follows

First the X ray films were divided into *two groups* according to whether the femoral head measured with Mose s plate proved to be *spherical* or *non spherical* The groups were designated SPH and NON sph Therafter the group SPH was sub divided – according to fixed measuring criteria – into two groups normal spherical and pathological spherical called NORM sph and PATH sph whose nature is apparent from the designations

According to the measurements on the X ray films each series was thus divided into three groups of patients NORM sph PATH sph and NON sph according to the radiological shape and size of the femoral head

Without a knowledge of the clinical consequences of the joint deformities in the three groups of patients the size of the group NORM sph was preliminarily considered a measure of the quality of the result According to the X ray films it had to be assumed that only patients of this group would be likely to remain free of osteoarthritis

ensitive to changes in the efficacy of the treatment

Briefly the main result of the radiological evaluation is

Application of the 3 methods in series composed like the wheelchair series (or like the bed rest or the traction series) gives on treatment with *traction* $1^1/_2$ times as many satisfactory (and only half as many poor) radiological results as bed rest or wheel chair treatment

(Two examiners measured the radiological deformities quite independently of each other Calculation of the radiological results on the basis of these two sets of measurements gave practically the same result (cf p 78 in particular Diagram 30))

What now are the *clinical consequences* of these radiological results?

Perusal of 19 previous reports on more or less late follow up studies of LCPD series treated by different methods revealed that radiological and clinical osteoarthritis was observed first and foremost in radiological group NON sph and in small numbers *but indubitably* also in group SPH (presumably only in PATH sph) – in the latter it is true not until the patients had reached a mean age of about 40

Later follow up studies of LCPD series are not available at present (yet vide infra)

The preliminary estimate that *only the group NORM sph would remain free of osteoarthritis* (at least up to the mean age of 40) *was thus confirmed*

At the same time however the investigation had shown that the cases of osteoarthritis that were found were mild and thus did not cause essential complaints – only about one third of the arthritic patients being more or less disabled

Now the problem was to ascertain the prognosis *beyond the latest follow up study* at a mean age of 40

Direct studies of LCPD series beyond this age were not available However investigation of large series of cases with secondary osteoarthritis – comprising also secondary osteoarthritis following upon diseases other than LCPD – showed in retrospect that in general secondary osteoarthritis develops according to a fairly uniform pattern regardless of the nature of the primary disease

The first symptom appeared

in 1/3 of the cases before the age of 40
in 1/3 of the cases between 40 and 50
in 1/3 of the cases after the age of 50

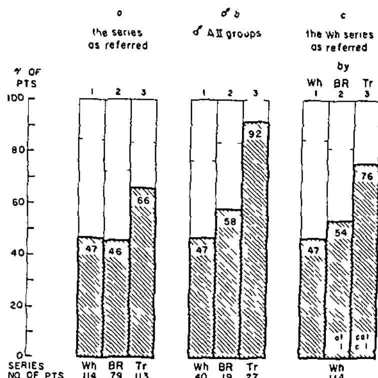
The time schedule shifts somewhat In the event of *severe* joint deformities the osteoarthritis sets in earlier – in more cases before the age of 40 – and in the event of *mild* deformities later – in more cases after 50

The largest material of osteoarthritis from which these data can be deduced is *Ruelle s (1961)* Indeed it also proved a good exponent for the result of the studies of others (Jerre 1950 Wiberg 1939 Danielsson 1964 Lloyd Roberts 1955 Lance 1937 and others)

Ruelle s material comprises 271 patients *who applied for treatment* of secondary osteoarthritis due to different causes (Thus the rate of osteoarthritis in his material is 100 %)

The time of onset of clinical symptoms of osteoarthritis (joint pain joint stiffness) could be mapped in retrospect with reasonable accuracy Thus it was possible to ascertain the percentage of the total cases of osteoarthritis developing prior to the 30th year of age and thereafter in the age groups 30–40 40–50 50–60 etc There by a total picture of the development of osteoarthritis could be obtained

This picture applies to Ruelle s mixed series but the values can be used also for drawing a picture of the development of osteoarthritis in pure LCPD series – provided that the deformities in these series with respect to arthritogenic effect are comparable with those in Ruelle s total mixed material or with those in one of his special groups Of course they are not



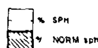


Diagram 33 Radiological results of treating

a	1 The Wh series as referred by Wh	(SPH	85 %)
	2 The BR series as referred by BR	(	73 %)
	3 The Tr series as referred by Tr	(	84 %)
♂b	1 The ♂A II group of the Wh series by Wh	(SPH	77 %)
	2 The ♂A II group of the BR series by BR	(	84 %)
	3 The ♂A II group of the Tr series by Tr	(	100 %)
c	1 The Wh series as referred by Wh	(SPH	85 %)
	2 The Wh series as referred by BR (calculated)	(	82 %)
	3 The Wh series as referred by Tr (calculated)	(	91 %)

(For a total survey of the radiological results cf Appendix Table 27 Abbreviations and symbols on p 12)

In other words it was possible to determine the efficacy of the three methods in the same total material (e g the wheelchair series) and thereby obtain a wider statistical basis Thus the inaccuracy in the individual smaller groups ought to be equalized to a certain extent

The result of this method for determining the radiological efficacy of the three forms of treatment is shown in Table 21 B

For comparison Table 21 A sets out the result of the evaluation performed in the three small uniform groups of patients (♂ A II) (cf also Diagram 33)

The reason why the difference in efficacy between the therapeutic methods is less marked in a total material than in the small uniform groups of patients is that a total material comprises cases with a very favourable and others with a very unfavourable prognosis – groups in which the results will be broadly speaking and regardless of the treatment *good or poor* respectively In the small uniform groups of patients on the other hand all cases are

series as the age distribution and joint deformity could be determined more precisely To avoid the effect of the different severity in the three series the development of osteoarthritis may be calculated int al as it would be after the use of the three therapeutic methods in three quite identical series composed like the wheel chair series

Diagram 34 gives the result of these calculations whose absolute presuppositions are the preceding sections on radiological and clinical evaluation

This diagram sets out in a perspicuous way *the main result of the present study*

The relative clinical efficacy of the three therapeutic methods in identical series of known composition – compared with the results of less effective methods in less known series

The relative – and absolute – efficacy of the three methods may be worded as follows

If a series of LCPD of approximately the same composition as the "wheelchair series is referred through a period of time to an orthopaedic department in this country the radiological joint deformities left after the treatment *be it wheelchair* bed rest or traction treatment will be so mild that no essential number of cases of clinically significant osteoarthritis will develop before the patients have attained the mean a of about *40* (cf also Diagram 28)

But after that age the development of osteoarthritis gains impetus At a mean age of about *50* almost *one third* of the surviving patients must be expected to have applied for treatment of osteoarthritis after *wheelchair treatment* rather more than *one-quarter* after *bed rest treatment* and about *one seventh* after *traction treatment*

Thereafter the development is slower After *wheelchair and bed rest* treatment osteoarthritis develops *in a maximum* of *one half* of the patients after *traction* in *one quarter* – and this *maximum* is not reached until the age of almost 70

In other words the *number of patients* who sooner or later have to apply for treatment of secondary osteoarthritis *after traction* is only half that after *wheelchair* treatment and *bed rest treatment* But the number of patients with osteoarthritis among the survivors does not reach a magnitude of essential importance after all forms of treatment until the patients have reached the mean age of *50*

In the present publication attention has constantly been drawn to the numerous pitfalls encountered while performing the calculations and the general uncertainty attaching to them

Therefore the apparently very precise predictions can only be taken with considerable reserve

Only the ratio between the values will presumably stand its test at late follow up studies (about the year of 2025)[1]

Several clinicians and child psychologists have claimed that the better results of traction therapy are too dearly bought by the long hospital treatment away from home

On the basis of considerable experience the present author does not agree – provided that the treatment is carried out in a suited institution (Appendix Comment 1)

The reason why ambulatory forms of treatment are preferred despite their indubitably poorer somatic results is most probably that such well-suited institutions are not available everywhere

After completion of the study reported above a *further follow up examination* (in collaboration with Mose et al) *was performed in 1974 of Helbo s previously followed patients* Regrettably only 25 could be traced These patients had at that time a follow up period of *more than 50 years*

According to *calculations* it would be expected that almost *90 %* of the patients surviving in 1974 would have applied for treatment because of osteoarthritic symp

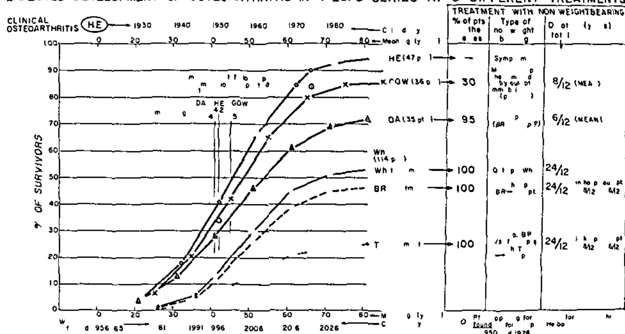


Diagram 34 Expected *development of osteoarthritis (presented for treatment) in the series of Helbo Gower & Johnston and Danielsson & Hernborg calculated by using figures from Ruelle s total material (I + II) and in 3 identical series composed like the Wh series having Wh BR or Tr treatment calculated by using figures from Ruelle s group II c % = % of survivors at the mean ages and calendar years stated*

For comparison the diagram gives the actual *% of survivors in Helbo s series who had applied for treatment of osteoarthritis at follow up in 1950 and 1974*

On the right of each series the % of patients in the series concerned who had received treatment *by non weightbearing – and the type of such treatment (in patient/out patient) as well as its duration*

I preferred showing the development of osteoarthritis with Wh BR and Tr treatment in 3 series composed like the Wh series as this clearly sets out the relative efficacy of the 3 treatments – the main problem of the present study

If the three curves at the bottom illustrated the development of osteoarthritis in the 3 series as referred their shape and situation would be affected by the fact that at institution of treatment the Wh series was prognostically more favourable than the BR and Tr series

The development of osteoarthritis in the Wh BR and Tr series as referred is shown in Table 18

directly commensurable but the comparison used ought to be reasonably probable

Knowing fairly well the maximum possible percentage of osteoarthritis in an LCPD series (e g the size of the groups PATH sph + NON sph) one can determine by the aid of Ruelle s figures the percentage of patients who have applied for treatment of osteoarthritis at a given time – provided that the age distribution at that time is known (Appendix Comment 5)

This possibility was first utilized for calculating by the aid of Ruelle s figures the expected osteoarthritis rate *at the time of follow up* in 3 of the latest follow up studies of LCPD series – Helbo s Gower & Johnston s and Danielsson & Hernborg s Thereafter the calculated and actual values were compared

As this showed reasonable agreement between the *calculated* and *actual* value it was felt justified to carry the calculations further into the future and fix the expected osteoarthritis rate 10 20 and 30 years after the latest follow up

At last the author arrived at *the central problem* The future development of osteoarthritis in the *wheelchair bed rest* and *traction series* which had been observed only up to the time of primary healing These calculations were carried out – and could even be carried out with greater accuracy than in the above mentioned

series as the age distribution and joint deformity could be determined more precisely To avoid the effect of the different severity in the three series the development of osteoarthritis may be calculated int al as it would be after the use of the three therapeutic methods in three quite identical series composed like the wheelchair series

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According to *calculations* it would be expected that almost 90 % of the patients surviving in 1974 would have applied for treatment because of osteoarthritic symp

EXPECTED DEVELOPMENT OF OSTEOARTHRITIS IN 4 LCPD SERIES AT 6 DIFFERENT TREATMENTS

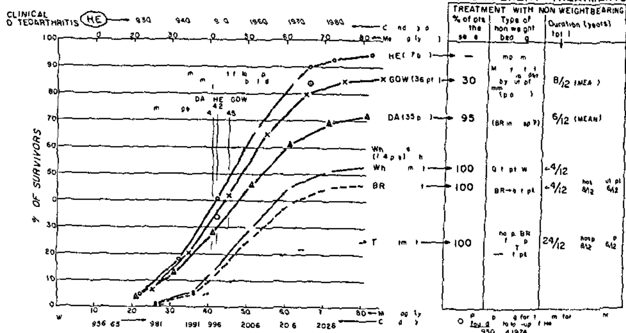


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% = % of survivors at the mean ages and calendar years stated

For comparison the diagram gives the actual *% of survivors in Helbo s series who had applied for treatment of osteoarthritis at follow-up in 1950 and 1974*

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This possibility was first utilized for calculating by the aid of Ruelle s figures the expected osteoarthritis rate *at the time of follow up* in 3 of the latest follow up studies of LCPD series – Helbo s Gower & Johnston s and Danielsson & Hernborg s Thereafter the calculated and actual values were compared

As this showed reasonable agreement between the *calculated* and *actual* value it was felt justified to carry the calculations further into the future and fix the expected osteoarthritis *rate 10 20 and 30 years* after the latest follow up

At last the author arrived at *the central problem* The future development of osteoarthritis in the *wheelchair bed rest* and *traction series* which had been observed only up to the time of primary healing These calculations were carried out – and could even be carried out with greater accuracy than in the above mentioned

tors as the age distribution and *joint deformity* could be determined more precisely. To avoid the effect of the *different* severity in the three series the development of osteoarthritis may be calculated t al as it would be after the use of the three therapeutic methods *in three quite identical series* composed like the wheel chair series

Diagram 34 gives the result of these calculations whose absolute presuppositions are the preceding sections on radiological and clinical evaluation

This diagram sets out in a perspicuous way *the main result of the present study*

The relative clinical efficacy of the three therapeutic methods in identical series of known composition – compared with the results of less effective methods in less known series

The relative – and absolute – efficacy of the three methods may be worded as follows

If a series of LCPD of approximately the same composition as the wheelchair series is referred through a period of time to an orthopaedic department in this country the radiological joint deformities left after the treatment be it wheelchair bed rest or traction treatment will be so mild that no essential number of cases of clinically significant osteoarthritis will develop before the patients have attained the mean age of about *40* (cf also Diagram 28)

But after that age the development of osteoarthritis gains impetus. At a mean age of about *50* almost *one third* of the surviving patients must be expected to have applied for treatment of osteoarthritis after *wheelchair treatment* rather more than *one quarter* after *bed rest treatment* and about *one seventh* after *traction treatment*

Thereafter the development is slower. After *wheelchair and bed rest* treatment osteoarthritis develops in a *maximum* of *one half* of the patients after *traction* in *one quarter* and this *maximum* is not reached until the age of almost 70

In other words the number of patients who sooner or later have to apply for treatment of secondary osteoarthritis *after traction* is only half that after *wheelchair* treatment and *bed rest treatment*. But the number of patients with osteoarthritis among the survivors does not reach a magnitude of essential importance after all forms of treatment until the patients have reached the mean age of *50*

In the present publication attention has constantly been drawn to the numerous pitfalls encountered while performing the calculations and the general uncertainty attaching to them

Therefore the apparently very precise predictions can only be taken with considerable reserve

Only the ratio between the values will presumably stand its test at late follow up studies (about the year of 2025)'

Several clinicians and child psychologists have claimed that the better results of traction therapy are too dearly bought by the long hospital treatment away from home

On the basis of considerable experience the present author does not agree – provided that the treatment is carried out in a suited institution (Appendix Comment I)

The reason why ambulatory forms of treatment are preferred despite their indubitably poorer somatic results is most probably that such well-suited institutions are not available everywhere

After completion of the study reported above a *further follow-up examination* (in collaboration with Mose et al) *was performed in 1974 of Helbo's previously followed patients*. Regrettably only 25 could be traced. These patients had at that time a follow up period of *more than 50 years*

According to *calculations* it would be expected that almost 90 % of the patients surviving in 1974 would have applied for treatment because of osteoarthritic symp

toms – which in these elderly patients would often have developed into a hip back syndrome

The actual finding was 84 %, cf Diagram 29

This agreement is so close that it must support confidence in the calculations concerning the development of osteoarthritis in the three series treated with wheelchair bed rest or traction

As already mentioned the correctness of these predictions cannot be checked until after the year of 2000

(A more detailed report of the results of this follow up study will be published elsewhere by Mose et al)

APPENDIX

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The actual finding was 84 %, cf Diagram 29

This agreement is so close that it must support confidence in the calculations con cerning the development of osteoarthritis in the three series treated with wheelchair, bed rest, or traction

As already mentioned the correctness of these predictions cannot be checked until after the year of 2000

(A more detailed report of the results of this follow up study will be published elsewhere by Mose et al)

COMMENTS

COMMENT 1

Normal Range of the Quotients

"The normal range of the epiphyseal quotient" is usually interpreted as the variation of the epiphyseal quotient *in normal children* – with normally shaped femoral heads – and thus the expression *can* be interpreted.

However, normally shaped femoral heads are found not only in *normal children*, but also in sick children, even in children with a history of hip disease – e.g. in *children with sequelae to LCPD*.

But it is the variation in cases with normally shaped femoral heads which is of interest in our context. Therefore the term "normal range of the epiphyseal quotient" is interpreted here in a somewhat wider sense, viz. as:

The variation of the epiphyseal quotient in children with normally shaped femoral heads.

However, the "normal range of the epiphyseal quotient" in this sense is not the same in a series of normal children and in a series of children having sequelae to LCPD. In *normal children*, all of whom have normally shaped femoral heads, the epiphyseal quotients come down to 85. In an *LCPD series* the epiphyseal quotients in cases with *normally shaped femoral heads* come down as far as 60. (*All* cases with epiphyseal quotient >60 – *and only these* – have normally shaped femoral heads.)

Therefore the term "normal range of the epiphyseal quotient" is used in the present paper only in the special sense:

Range of the epiphyseal quotient in children with normally shaped femoral heads in an LCPD series.

It is only a knowledge of this range which is of interest in evaluating the therapeutic results in an LCPD series.

The range of the *joint surface quotient* in LCPD patients with normally shaped femoral heads and the range of the *radius quotient* in LCPD patients with femoral heads of normal shape and size, on the other hand, are equal to the ranges in normal children (>85 and <115 respectively).

Thus, in an LCPD series the quotients are within the normal range when the *epiphyseal quotient* >60, the *joint surface quotient* >85 and the *radius quotient* <115.

COMMENT 2

Comparison of the Evaluations of Radiological Results of Treatment by 1 Measuring Method ("1-quotient assessment") and by a Combination of 3 Measuring Methods ("3-quotient assessment")

In the present study the radiological assessment was done by dividing the series into three groups of patients: NORM sph, PATH sph and NON-sph.

First the series were divided by the aid of Mose's plate into two groups – SPH and NON-sph. Thereafter SPH was sub-divided into two groups, NORM sph and PATH sph, by means of *three* measuring methods determining three quotients for each patient: joint surface quotient, epiphyseal quotient and radius quotient.

ment using SPH the results appear to be better (higher percentages) and the differ er.es between the therapeutic methods get less marked than in the stricter 3-quotient assessment

These differences are easy to spot but the *similarity* of the results found by the four assessments is p rhaps even more *striking* The four diagrams (I–IV) are of a striking uniformity all showing considera*bly better results of traction* than of wh el hair or bed rest treatment and the differences between these therapeutic results are at least of approximately the same magnitude with all four evaluations

The reason why the more complicated 3-quotient assessment was preferred in the present study is that it is more reliable

Three criteria secure much better than one that cases singled out as NORM sph really live up to their name With the use of 1 criterion the most peculiar femoral heads may at times slip into the group

Besides the effect of special difficulties of measurement and other sources of error attaching to the individual measuring methods will be to some extent equalized by a combination of three measuring methods

Nevertheless the 1-quotient assessment may be highly applicable as an easy preliminary orientation at primary healing

For such assessment the radius quotient is perhaps best suited In the first place measurement of the radius quotient is so simple that the risk of measuring errors must be less than in the other more complicated methods. In the second place it is apparent from Diagrams 35 and 36 that the results of assessing by this quotient alone is – quantitatively – closest to the results of the 3-quotient assessment The slight difference is due to the fact that apart from the cases in "NORM sph the "NORM sph (RA) comprises cases with a change in the shape of the head without any increase in growth

However it is a presupposition for using the radius quotient that the *age distribution* and *follow-up periods* are *approximately the same* – as in the present series *And this is a demand which is not so easy to fulfill*

But if this condition is fulfilled the measurements needed for this 1-quotient assessment must be said to be very simple A basis for an evaluation is obtainable merely by placing *Mose s plate* over the femoral head on the X ray film and recording the length of the radius for the spherical heads

It can hardly be simpler

The above may perhaps urge busy clinicians to attempt a *preliminary* evaluation of their therapeutic results However *it must be emphasized that the 3-quotient*

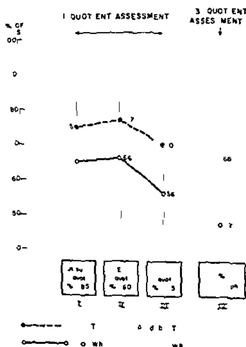


Diagram 36 Results in the Wh and Tr series at referred assessed by 1 measuring method – 1-quotient assessment (I II III) and by a combination of 3 measuring methods – 3-quotient assessment (IV)

I Assessment by the jo nt surface quotient
II Assessment by the epiphyseal quotient
III Assessment by the rad us quotient
IV Assessment by a combination of all 3 measuring methods – % NORM sph

This diagram is a more instructive and perspicuous edition of Diagram 35 (omitting the BR results)

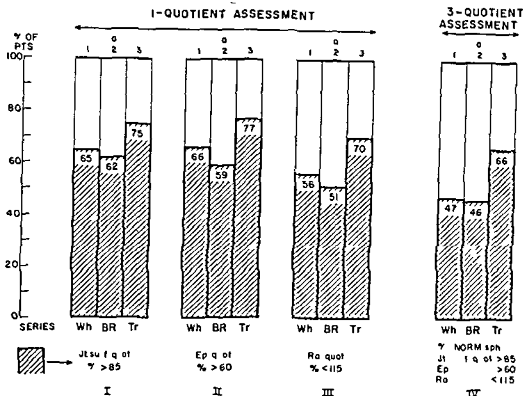


Diagram 35 Results in the series as referred (a) assessed by only one measuring method – 1-quotient assessment *– and by a combination of 3 measuring methods –* 3-quotient assessment

a { *1 Wh series as referred (114 pts) treated by Wh*
2 BR series as referred (79 pts) treated by BR
3 Tr series as referred (113 pts) treated by Tr }

I Assessment by the joint surface quotient
II Assessment by the epiphyseal quotient
III Assessment by the radius quotient
IV Assessment by a combination of all 3 measuring methods – % NORM sph

Tables 22 23 and 24 in the Appendix set out the joint surface epiphyseal and radius quotients in the three series

When all three were within the normal range the case was assigned to NORM sph

This sounds fairly complicated – and may indeed deter a clinician who wants to assess his results

Considerable simplification would be obtained by performing the assessments exclusively by the aid of *one* quotient instead of three

Diagram 35 gives the results in the three series as referred when the cases with normally spherical heads are singled out by using 1 quotient (I–II–III) and by using 3 quotients (IV)

It will be seen that the results of the 1 quotient assessment are on a higher level than those of the 3 quotient assessment and that the differences between the results in the three series appear to be less marked This is particularly evident from Diagram 36 which shows the results only for the wheelchair and traction series Diagram 35 shows that this pattern may be broken The differences between the bed rest and wheelchair results in the 3 quotient assessment are less marked than expected

These differences between the results of 1 quotient assessment and 3 quotient assessment are naturally explained by the fact that in the 1 quotient assessment the demands on a satisfactory result have been reduced Therefore as in the assess

second follow up 12 years later was some what less pronounced (Ratliff's second publication) the percentage of SPH was fixed as about 48 % – somewhat higher than the percentage of practically speaking normal heads in this selected group of patients about 44 %

COMMENT 4

Spread Fixing the Percentage of the 19 Series Over Which Cases of Radiological Osteoarthritis and Subjective Arthritic Symptoms Spread When the Series Are Arranged by Increasing Primary Joint Deformity – e g as in Diagram 18 – from Left to Right

For each series then two spread rates are to be fixed – one for radiological osteoarthritis and one for subjective symptoms.

Below the procedure in the five series with longest follow up will be described In principle it is the same as in fixing the "spread rate in the remaining 14 series but space does not permit a detailed description of the procedure in these 14 series

In the five series thus there are 10 spread rates to fix

Series No 1 Helbo
(a) *Radiological osteoarthritis* 56 % of the patients exhibited signs of radiological osteoarthritis According to Helbo himself these 56 % were distributed (spread) over two of the groups into which he divided his material and classified by him – a cording to the primary radiological de formity – as greatly flattened and ir reg. On the other hand Helbo found no signs of radiological osteoarthritis in his third group designated spherical The two groups greatly flattened and irreg combined make up 88 % of the total series Accordingly the 56 % patients having ra diological osteoarthritis are spread over 88 % of the series

In other words the spread rate of radiological osteoarthritis is *apparent direct from Helbo s data*.

(b) *Subjective symptoms* The spread rate of such symptoms is found on the basis of exactly the same reasoning as that of radiological osteoarthritis 62 % of the pa tients had symptoms (mostly joint pain) distributed – like the signs of radiological osteoarthritis – over 88 % of the series whereas 12 % (the group spherical) were symptom free

For the remaining 4 series a total of 8 spread rates have to be determined

Thereamongst 5 can be determined as in Helbo s series *directly on the basis of data given by the four authors*

However a comment is required with respect to series No 3 (Gower & John ston s) In this series radiological osteo- arthritis and subjective symptoms were found to be spread over *all* groups although in the round group with least deformity there was only one patient with radiological osteoarthritis and one with subjective symptoms (pain) i e each making up one sixth of this group The spread in this group then was taken to be one third – giving a spread rate for the entire series of 86 %

The last three spread rates in these four series cannot be determined *direct* on the basis of information given by the authors the percentage of osteoarthritic patients being stated only for the total series – not for individual groups

method used in the present study is more reliable – and it sets out the difference in the efficacy of the treatments better than do the less strict I quotient assessments At least this has been observed in the present three series

COMMENT 3

Fixing %"SPH" in Series Nos 1–5 Seen at Follow up (Helbo Sundt ii Gower & Johnston Danielsson & Hernborg and Ratliff)

Series No 1 The percentage of "SPH" in Helbo's series was fixed as about *12–13 %*

Helbo and I have previously used the same measuring methods for evaluating the therapeutic result in one series treated by bed rest and have thereby arrived at the same result (Meyer 1966) Accordingly I was able to evaluate Helbo s classification of his series This showed that the groups greatly flattened' and irregular combined correspond to my group NON sph whereas his group spherical corresponds to my SPH – which makes up about 12 5 % of his total series

Series No 2 The percentage of SPH in Sundt s series was estimated at *about 27 %*

According to the text of Sundt s paper the group 'spherical corresponds approximately to my NORM sph The group ovoid is characterized as favourably healed As Sundt cannot have used this term for cases which had healed with irregular non spherical heads (the group NON sph) which are invariably greatly deformed at least the greater part of his cases in the ovoid group must belong to SPH To arrive at a minimum value only half the ovoid group was assigned to SPH which thus makes up about 27 % of the total series (between 20 35 %)

Series No 3 The percentage of SPH in Gower & Johnston s series was estimated at *about 30 %* This assessment *is uncertain* According to the X ray films shown (and the group designation) the cases of the round group (20 %) correspond to the better part of SPH (approximately to ' NORM sph) It is difficult to say how many of the large group flattened (73 %) have poorly spherical heads with a long radius I have calculated 10/73 SPH in this group – presumably too low Thus out of the entire series SPH ought to make up (at least) 30 %

Series No 4 The percentage of SPH in Danielsson s and Hernborg s series was estimated at *about 35 %* Their classification is illustrated by 4 X ray films showing the least deformed joint of each group According to the appearances there is no doubt that group 0 and at least part of the cases in group I have healed with spherical heads (SPH) Judging by the X ray films (*and the small drawings from* the films of each case) it may be estimated that 3/4 of the cases in group I belong to SPH so that the percentage of SPH in the entire series is about 35 %

Series No 5 The percentage of SPH in Ratliff s series was estimated at *about 48 %* His series is not classified according to purely radiological but according to a *combination of radiological and clinical* criteria However it is explicitly mentioned in Ratliff s first publication that in 52 % of the cases the femoral head was appreciably deformed and in 40 % practically *normal* As the deformity of the heads in the selection of patients who were seen at a

second follow up 12 years later was some what less pronounced (Ratliff's second publication) the percentage of SPH was fixed as about 48 % – somewhat higher than the percentage of practically speaking normal heads in this selected group of patients about 44 %

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Spread Fixing the Percentage of the 19 Series Over Which Cases of Radiological Osteoarthritis and Subjective Arthritic Symptoms Spread When the Series Are Arranged by Increasing Primary Joint Deformity – e g as in Diagram 18 – from Left to Right

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Below the procedure in the five series with longest follow up will be described In principle it is the same as in fixing the "spread rate in the remaining 14 series but space does not permit a detailed description of the procedure in these 14 series

In the five series thus there are 10 spread rates to fix

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(a) *Radiological osteoarthritis* 56 % of the patients exhibited signs of radiological osteoarthritis According to Helbo himself these 56 % were distributed (spread) over two of the groups into which he divided his material and classified by him – according to the primary radiological de formity – as greatly flattened and ir reg. On the other hand Helbo found no signs of radiological osteoarthritis in his third group designated spherical The two groups greatly flattened and irreg combined make up 88 % of the total series Accordingly the 56 % patients having ra diological osteoarthritis are spread over 88 % of the series

In other words the spread rate of radiological osteoarthritis is *apparent direct from Helbo s data.*

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For the remaining 4 series a total of 8 spread rates have to be determined

Thereamongst 5 can be determined as in Helbo s series *directly on the basis of data given by the four authors*

However a comment is required with respect to series No 3 (Gower & John ston s) In this series radiological osteo- arthritis and subjective symptoms were found to be spread over *all* groups although in the round group with least deformity there was only one patient with radiological osteoarthritis and one with subjective symptoms (pain) i e each making up one sixth of this group The spread in this group then was taken to be one third – giving a spread rate for the entire series of 86 %

The last three spread rates in these four series cannot be determined *direct* on the basis of information given by the authors the percentage of osteoarthritic patients being stated only for the total series – not for individual groups

This applies to subjective symptoms in Sundt's series II and to radiological osteo arthritis as well as subjective symptoms in Ratliff s

SU_{II} Symptoms in the form of *joint pain* were found *in 55 % of the patients of* this series – i e , without spread in all patients of the groups 'cylindrical' and angular' (which total exactly 55 %) It is beyond doubt, however, that there must be a spread' of patients with symptoms – *and that this spread must then comprise at* least half the group 'ovoid which makes up together with the two groups mentioned above 73 % of the entire series This is then the spread rate of subjective symp toms in the form of *joint pain* Since, *however, the percentage of these subjective* symptoms in the entire series is practically the same as that of radiological osteo arthritis (55 %/58 %) and since according to Sundt himself radiological osteoarthritis spread over the entire ovoid" group there *is a predominant* likelihood that the subjec tive symptoms in the form of pain, also spread over the same area This is beyond doubt, if *a limp* is included among the subjective symptoms A limp was found in 67 % of the patients – far into the ' ovoid group True, a limp is not a sure sign of osteoarthritis, but at least it is a sequel to the primary LCPD and a sequel which may be a great subjective strain on the patients

In accordance with these reflections, it is assumed that the subjective symptoms, like the radiological signs of osteoarthritis, were spread over *91 %* of Sundt s series

Ratliff In this series information is yielded only about the percentage of all *patients in the series who had radiological* osteoarthritis and subjective symptoms – 50 % and 20 % respectively These rates are only slightly lower than the percentages of the groups fair + poor' and 'poor' respectively The spread rates were there *fore fixed as the size of these two groups of* patients i e 55 % and 23 % respectively In actual fact, however they are presumably somewhat higher

As already mentioned, the spread rates *in* the other 14 series were determined according to exactly the same principles as those used for the five series with the longest follow up periods

COMMENT 5

Ruelle's Figures and Their Use in Predicting the Development of Osteoarthritis in LCPD Series

Hip deforming diseases – congenital or running their course during childhood – are followed by a certain number of cases of secondary osteoarthritis The percentage depends largely upon *the extent of the* joint deformities left by the disease

A material of such secondary osteo arthritis (271 patients presumably not selected according to age) following upon various hip deforming diseases has been analysed by *Ruelle* with a view to the age at *which the osteoarthritis (subjective* symptoms of osteoarthritis) set in

He found that

about 1/3 had started before the 40th birthday
about 1/3 had started between the 40th and 50th birthday
and 1/3 had started after the 50th birthday

More detailed findings were that

100 %	had developed symptoms of osteoarthritis before the	80th birthday
99 %	"	70th
93 %		60th
70 %		50th
36 %		40th
10 %		30th
2 %		20th

These figures then refer to cases of osteoarthritis developing after the mixture of mild moderate and severe deformities present in Ruelle s total series – deformities probably on the average moderate In series with a larger number of mild deformities a smaller part of the cases of osteoarthritis – e g 1/5 – will start before the 40th birthday and a larger part e g 1/2 after the 50th birthday The reverse will apply to series containing a larger number of severe deformities

Cf also the values listed for Ruelle s special groups (Table 12)

As already mentioned Ruelle s cases of osteoarthritis were the sequelae to several different hip-deforming diseases However the picture of the development of osteoarthritis might easily have been exactly the same if all the cases were sequelae to LCPD – provided that the hip deformities corresponded with respect to arthritogenic effect to those in Ruelle s series

We shall now follow from the time of primary healing an LCPD series in which the development of osteoarthritis occurs in conformity with the figures from Ruelle s total series and in which all patients are potential osteoarthritics

If the patients of such a series are examined say when they *pass their 40th birthday* the examination will show that about 1/3 of the total cases of osteoarthritis that will develop in the series have started before the 40th birthday

It is evident that if no patient died before the 40th birthday one third of the examined (surviving) patients would have symptoms of osteoarthritis

But of course some patients – though few – die before the 40th birthday The majority will die without signs of osteoarthritis and only a minority have had time to develop signs of osteoarthritis before dying – i e they die with osteoarthritis

Since however *the mortality is the same* in patients with and without osteoarthritis the osteoarthritis rate among the survivors on the 40th birthday will be the same as if none had died

In other words

When 1/3 of the final number of cases of osteoarthritis set in before the 40th birthday this means that 1/3 of the survivors have osteoarthritis at that time

The same rule – *only using another fraction* – *naturally applies also if the examination has been carried out at any other age e g 50 60 or 70*

(The *potential* osteoarthritic patients who *die before the expected osteoarthritis has developed* of course reduce the final rate of osteoarthritis

However *this reduction is not more than 4–6 % of the final cases In practice this must be said to be immaterial considering the uncertainty of the deformity criteria by which the group of final osteoarthritis ' is selected In the traction series for instance there is a question of only 2 patients (cf Diagram 37))*

Final osteoarthritis *makes up a varying percentage of the patients in the various LCPD series – hardly ever 100 % as in the above example*

Thus *if the final osteoarthritis rate is* 60 % of the original series at primary

This applies to subjective symptoms in Sundt s series II and to radiological osteo arthritis as well as subjective symptoms in Ratliff s

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In accordance with these reflections it is assumed that the subjective symptoms like the radiological signs of osteoarthritis, were spread over *91 %* of Sundt s series

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As already mentioned, the spread rates in the other 14 series were determined according to exactly the same principles as those used for the five series with the longest follow up periods

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He found that

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about 1/3 had started between the 40th and 50th birthday
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More detailed findings were that

100 % had developed symptoms of osteoarthritis before the 80th birthday
99 % ... 70th
93 % ... 60th
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These figures then refer to cases of osteoarthritis developing after the mixture of mild, moderate and severe deformities present in Ruelle's total series – deformities probably on the average moderate. In series with a larger number of mild deformities a smaller part of the cases of osteoarthritis – e.g. 1/5 – will start before the 40th birthday and a larger part, e.g. 1/2, after the 50th birthday. The reverse will apply to series containing a larger number of severe deformities.

Cf. also the values listed for Ruelle's special groups (Table 12).

As already mentioned, Ruelle's cases of osteoarthritis were the sequelae to several different hip-deforming diseases. However, the picture of the development of osteoarthritis might easily have been exactly the same if all the cases were sequelae to LCPD – provided that the hip deformities corresponded with respect to arthritogenic effect to those in Ruelle's series.

We shall now follow, from the time of primary healing, an LCPD series in which the development of osteoarthritis occurs in conformity with the figures from Ruelle's *total* series and in which *all* patients are potential osteoarthritics.

If the patients of such a series are examined, say, when they *pass their 40th birthday*, the examination will show that about 1/3 of the total cases of osteoarthritis that will develop in the series have started before the 40th birthday.

It is evident that if no patient died before the 40th birthday one third of the examined ("surviving") patients would have symptoms of osteoarthritis.

But of course some patients – though few – die before the 40th birthday. The majority will die without signs of osteoarthritis and only a minority have had time to develop signs of osteoarthritis before dying – i.e. they die with osteoarthritis.

Since, however, the mortality is the same in patients with and without osteoarthritis, the osteoarthritis rate among the survivors on the 40th birthday will be the same as if none had died.

In other words:

When 1/3 of the final number of cases of osteoarthritis set in before the 40th birthday, this means that 1/3 of the *survivors* have osteoarthritis at that time.

The same rule – only using another fraction – naturally applies also if the examination has been carried out at any other age, e.g. 50, 60 or 70.

(The *potential* osteoarthritic patients who *die before the expected osteoarthritis has developed* of course reduce the final rate of osteoarthritis.

However, this reduction is not more than 4–6 % of the final cases. In practice this must be said to be immaterial considering the uncertainty of the deformity criteria by which the group of "final osteoarthritis" is selected. In the *traction* series, for instance, there is a question of only 2 patients (cf. Diagram 37).)

Final *osteoarthritis* makes up a varying percentage *of the* patients in the various LCPD series – hardly ever 100 % as in the above example.

Thus if the final osteoarthritis rate is 60 % of the original series at *primary*

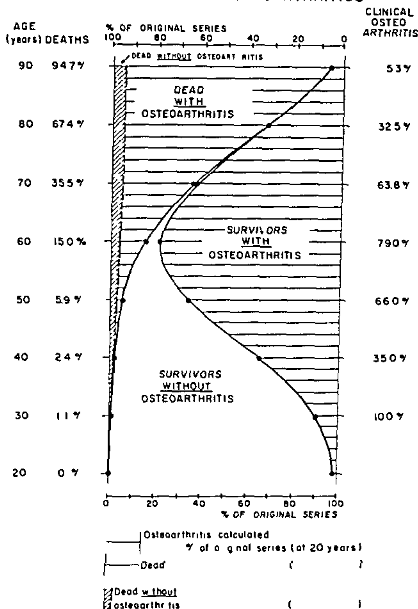


Diagram 37 Development of clinical osteoarthritis presented for treatment in an LCPD series in which all patients must be considered potential osteoarthritics because of the severity of the articular joint deformities

Calculation based upon Ruelle s total material (I + II)

The calculated osteoarthritis rates signify osteoarthritis in survivors when passing the listed birthday expressed in per cent of the original material at the age of 20 years

Mortality curve in relation to the age of 20 years Stat Årbog Denmark 1968

From this diagram it is possible to read for each age (birthday)

% survivors without osteoarthritis
% survivors with osteoarthritis
% dead with osteoarthritis
% dead without osteoarthritis – i e dead before clinical symptoms of osteoarthritis have appeared

healing 20 % have started before the 40th birthday and among the survivors 20 % have osteoarthritis (still using the figures of Ruelle s *total* material) With figures from Ruelle s less deformed groups the percentage is <20 and with figures from his more deformed groups >20

It was now attempted *to single* out such a group of final osteoarthritis – i e potentially osteoarthritic pat ents – from the *wheelchair bed rest and traction series* on the basis of the radiological deformity at primary healing All patients of the deformity groups *NON-sph* " and *PATH* sph were assigned *to this group*

If a reasonably reliable estimate re garding the number of potential osteoarthritis at primary healing – and thereby regarding the final maximum osteoarthritis rate to be expected – has been made *in an LCPD* series Ruelle s figures ought to be applicabl as described above *for predic* ting the osteoarthritis rate that will be found among the survivors at a given age

So far the discussion has concerned only the osteoarthritis rate at *a given age* 40 50 and 60 etc

To ascertain the osteoarthritis rate at a given time – e g at a possible follow up *examination* – regard must be paid to the fact that at a given time the patients will *differ in age Say for instance that the age* distribution *is from 40 to 50* at the time of followup *the number of patients with* osteoarthritis among these survivors can be calculated with approximation by using the mean of the osteoarthritis rates at 40 and 50 (i e 53 % in deformities corresponding to those in Ruelle s total series and 100 % final osteoarthritis)

In extreme age groups however the mean cannot be used without correction

Of course the same procedure is applica ble when the age distribution is over *several* 10-year periods Only in that event the calculated number of patients with osteoarthritis in each 10-year period must be added and related to the total number of surviving patients

This is the procedure used for the majority of the calculations in the clinical section – first to check the method in *series already seen at follow-up* (Helbo Gower & Johnston and Danielsson & Hernborg) and thereafter when the meth od had proved reasonably applicable for predicting the osteoarthritis rates at in creasing mean ages in the series already seen at follow up as well as in those not yet followed up viz the *wheelchair bed rest and traction series*

Which are the degrees of severity of osteoarthritis to which Ruelle s figures refer?

It is characteristic of Ruelle s patients that all had sooner or later *applied for treatment* of osteoarthritis

Ruelle s series was divided into 10-year *age groups according to the* onset of *osteoarthritis* (20–30 years 30–40 years etc)

It seems likely that the *majority* of *patients whose symptoms of osteoarthritis* have set in *within such a* 10-year period *have also applied for treatment before the expiry of this relatively long period* Only *a minority develop their symptoms of* osteoarthritis *at such a late stage of the period that they have not applied for treatment before its expiry*

If this is true at the expiry of the earliest *10-year period (e g 20–30 years)*, it must be even more true of the osteoarthritis rates calculated at older ages The fact is that these calculations were based on pa tients with osteoarthritis from all the pre ceding 10-year periods – i e a number of patients increasing in the course of the years Since *all* patients from the preceding 10-year periods have gradually applied for treatment the part – percentage – of patients who have *not* applied for treat ment will *decrease in* the course of time – to a very low percentage

Thus it appears *likely* that the majority of Ruelle s patients applied for treatment within the 10-year period in which their osteoarthritis set in However we do not know this for certain as Ruelle does not state the time interval between the onset of symptoms and the institution of treatment

Whether it is true depends upon whether Ruelle counts only the time at onset of

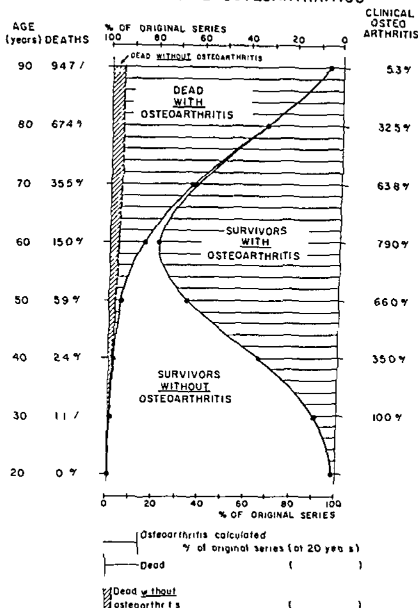


Diagram 37 Development of clinical osteoarthritis presented for treatment in an LCPD series in which all patients must be considered potential osteoarthritics because of the severity of the articular joint deformities

Calculation based upon Ruelle s total material (I + II)

The calculated osteoarthritis rates signify osteoarthritis in survivors when passing the listed birthday expressed in per cent of the original material at the age of 20 years

Mortality curve in relation to the age of 20 years Stat Årbog Denmark 1968

From this diagram it is possible to read for each age (birthday)

% survivors without osteoarthritis
% survivors with osteoarthritis
% dead with osteoarthritis
% dead without osteoarthritis – i e dead before clinical symptoms of osteoarthritis have appeared

healing 20 % have started before the 40th birthday and among the survivors 20 % have osteoarthritis (still using the figures of Ruelle s *total* matercal) With figures from Ruelle s less deformed groups the percentage is <20 and with figures from his more deformed groups >20

osteoarthritis rate would correspond in all essentials to the percentage of osteoarthritis presented for treatment in Helbo s material (34 %) not to the higher percentage (6? %) of all cases of clinical osteoarthritis found by him

But which of Ruelle s groups is suited f r su h a calculation?

Ruelle s *total* material comprises patients with all kinds of primary deformity – mild as well as severe but presumably predominantly severe – following upon congenital dislocation subluxation epiphysiolysis and (a few) LCPD

Helbo s series which consists of untreated LCPD cases is also a predominantly severely deformed material

A priori it might be assumed therefore that the deformities in Ruelle s total series would correspond in arthritogenic effect quite well to those in Helbo s series (like the deformities in the special groups of patients closest to the middle epiphysiolysis LCPD and subluxation)

Using the figures from Ruelle s total material for the calculation the rate therefore ought to correspond quite well to Helbo s percentage of osteoarthritis that had been presented for treatment and should preferably be *somewhat higher!*

This proved to be entirely true The calculated osteoarthritis rate was 41 % the actual rate 34 %

Thus the deformities in Ruelle s total material (RU I–II) seem to correspond well to those in Helbo s – that is if Ruelle s values as substantiated above refer to patients who have applied for treatment of their osteoarthritic symptoms

The correctness of this supposition is also indicated by the following There is a striking difference in the percentage of clinical osteoarthritis found at follow-up examination of Helbo s series 62 % – and at follow up examination of Danielsson & Hernborg s LCPD series – which was only 23 % It is striking because the mean age (and the age distribution at onset of the disease) is the same in both series and because the treatment of both series had been of little efficacy – (somewhat better in Danielsson & Hernborg s viz 6 months non weightbearing against at most 3 months in Helbo s)

On the other hand the percentage of *radiological* osteoarthritis was approximately the same in both series Danielsson & Hernborg s *50 %* and Helbo s *56 %* This small difference is perhaps explicable by the somewhat more effective treatment of Danielsson & Hernborg s series – but this explanation can by no means account for the enormous difference between the clinical cases of osteoarthritis in the two very similar series

The only conceivable explanation is that Helbo s clinical osteoarthritis did not signify the same as Danielsson & Hernborg s comprising a far larger number of mild cases than Danielsson & Hernborg s

Possibly their criteria of clinical osteoarthritis do not differ much in theory but in practice they function very differently Indeed it is (almost) impossible to set up a definite objective criterion of clinical osteoarthritis

Below the term criteria refers exclusively to their function in practice

Thus Danielsson & Hernborg s criteria of clinical osteoarthritis appear to be far stricter than Helbo s

But plotting of 3 curves for the development of clinical osteoarthritis in three large series of predominantly *primary* osteoarthritis reported by Ruelle Danielsson and Graber Duvernay shows that these curves practically coincide (Ruelle 1961 Danielsson 1964 Graber Duvernay (quoted by Francon 1956) (Diagram 38))

This can in fact only be interpreted to the effect that the three authors have had the same criterion of clinical osteoarthritis – in particular that in practice Danielsson s and Ruelle s has been the same

However the results of the follow up examination of secondary osteoarthritis

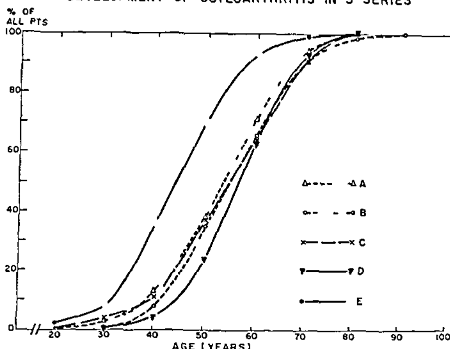


Diagram 38 Development of osteoarthritis in 5 different series of osteoarthritis affecting the hip
The points on the curves signify the percentage of cases of osteoarthritis causing symptoms before the age stated

A Primary + secondary osteoarthritis – Ruelle *(patient groups I II III IV and V) 924 pts 1961*
B Osteoarthritis – presumably primary + secondary A Graber Duvernay *quoted by Francois Francon 1067 pts 1956*
C Primary + secondary osteoarthritis Danielsson *1964 115 pts data from patient list p 98*
D Primary osteoarthritis Ruelle *(patient groups III IV and V) 653 pts 1961*
E Secondary osteoarthritis Ruelle *(patient groups I + II) 271 pts 1961*

symptoms which really troubled the patient – and therefore rapidly led to treatment – or whether he included also the mildest symptoms – which a patient may have for years without applying for treatment

Ruelle s study is evidently an analysis *based upon case notes* (through several years) concerning the time at onset of osteoarthritis – and not the result of a follow up examination Such an analysis is likely to afford information only about the *onset of osteoarthritis symptoms* which constitute a real complaint and therefore have made the patient apply for treatment – and not about milder symptoms which the patient does not remember and to which he had not attached any importance

It is different with a *follow up examination* in which even mild symptoms are easier to disclose by an interested and careful examiner

For instance in Helbo s follow up examination in 1950 when the patients mean age was 42 62 % had clinical symptoms of osteoarthritis but only about half of these (34 %) had applied for treatment Helbo expressly states that the symptoms were very mild and of little significance to the patients especially among those who had not applied for treatment

Thus apart from the long 10 year intervals Ruelle s type of analysis indicates that his figures refer only to osteoarthritis causing symptoms of such severity that the patients had applied for treatment

If we calculate on this presupposition the expected osteoarthritis rate in Helbo s series at the time of follow up by means of figures from that of Ruelle s groups of diseases in which the primary deformity corresponds to that in Helbo s series the result ought to be that the calculated

osteoarthritis rate would correspond in all essentials to the percentage of osteoarthritis presented for treatment in Helbo s material (34 %) not to the higher percentage (62 %) of all cases of clinical osteoarthritis found by him

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However the results of the follow up examination of secondary osteoarthritis

showed, as already mentioned that Danielsson s criterion also used by Danielsson & Hernborg must be considerably stricter than *Helbo s*

This, then, must apply also to Ruelle s criterion — just what had to be expected if it is correct that Ruelle s rates unlike Helbo's refer exclusively to osteoarthritis of a severity so that the patients soon apply for treatment

The course of the curves confirms that this *is* correct

The similarity of Danielsson s and Ruelle s criteria of clinical osteoarthritis also explains why the calculated percentage in Danielsson & Hernborg s material corresponds to the percentage of *all* clinical cases of osteoarthritis found – 28 %/23 % – and not as in Helbo s series to only *a fraction* of them, viz those presented for treatment – 41 %/34 %

The two fractions are equal = 1 2 – which might indicate that Danielsson s criterion of clinical osteoarthritis corresponds quite accurately to what characterizes the cases of osteoarthritis presented for treatment in Helbo s series

These curves are highly informative and afford further support to the other arguments that the percentage of osteoarthritis calculated on the basis of Ruelle s figures refers in all essentials *only to the percentage of osteoarthritis presented for treatment*

TABLES AND CHARTS*)

Table ? Epiphyseal quotients joint surface quotients and radius quotients in 114 patients who had ambulatory wheelchair treatment (Orthopaedic Hospital Å hus 1959–64 incl)

	Number	%
Total patients	114	100
Patients with *spherical* femoral heads	97	85
Patients with *non spherical* femoral heads	17	15

Within the group of patients with spherical heads

1

Epiphyseal quotient	No of pts.	% of all pts
100 96 incl	6	5 2
100 91 incl	15	13 1
100 86 incl	24	21 0
100 81 incl	32	27 2
100 6 incl	41	36 0
100 71 incl	52	45 5
100 66 incl	63	55 3
100 61 incl	75	65 7
100 56 incl	79	69 3
100 51 incl	86	[illegible]5 5
100 46 incl	88	77 2
100 41 incl	93	81 5
100 36 incl	96	84 0
100 31 incl	97	85 0

2

Joint surface quotient	No of pts.	% of all pts.
110–106 incl	2	1 7
110–101 incl.	12	10 5
110– 96 incl	9	25 4
110– 91 incl	52	45 5
110– 86 incl.	74	65 0
110 81 incl.	85	74.5
110– 76 incl	89	78 0
110– 71 incl.	96	84 0
110– 66 incl	97	85 0

3

Radius quotient	No of pts	% of all pts.
90– 94 incl	1	0 9
90– 99 incl	0	0 9
90–104 incl.	23	20 2
90–109 incl	49	43 0
90–114 incl	64	56 0
90–119 incl	76	66 7
90–124 incl	83	73 0
90–129 incl	87	76 2
90–134 incl	92	80 6
90–139 incl	95	83 3
90–144 incl.	95	83 3
90–149 incl	95	83 3
90–154 incl.	96	84 0
90–159 incl.	97	85 0

NORM sph 54 pts 47 3 % "PATH sph" 43 pts. = 37 7 %

*)CHARTS p 114 118

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ble 4 Epiphyseal quotients joint surface quotients and radius quotients in 113 patients treated by traction in bed *efinas 1958–63)*

	Number	%
Total patients	113	100
Patients with *spherical* femoral heads	95	84
Patients with *non spherical* femoral heads	18	16

Within the group of patients with spherical heads

1

Epiphyseal quotient	No of pts	% of all pts
115 111 incl	2	1 8
115 106 incl	2	1 8
115 101 incl	3	2 6
115 96 incl	10	8 9
115 91 incl	24	21 2
115 86 incl	38	33 6
115 81 incl	56	49 5
115 76 incl	69	61 0
115 71 incl	81	71 6
115 66 incl	86	76 0
115 61 incl	87	77 0
115 56 incl	92	81 3
115 51 incl	94	83 0
115 46 incl	94	83 0
115 41 incl	95	84 0

2

Joint surface quotient	No of pts	% of all pts
110–106 incl	2	1 8
110–101 incl	10	8 8
110– 96 incl	40	35 4
110– 91 incl	66	58 4
110– 86 incl	85	75 2
110– 81 incl	90	79 6
110– 76 incl	92	81.5
110– 71 incl	95	84 0

3

Radius quotient	No of pts	% of all pts
95– 99 incl	3	2.6
95–104 incl	48	42.5
95–109 incl	71	62 8
95–114 incl	79	70 0
95–119 incl	86	76 0
95–124 incl	91	80 5
95–129 incl	94	83 0
95–134 incl	95	84 0

NORM sph = 75 pts = 66 % PATH sph." 20 pts = 18 %

Table 23 Epiphyseal quotients joint surface quotients and radius quotients in 79 patients treated by bed rest without traction *(Refsnæs 1953–57)*

	Number	%
Total patients	79	100
Patients with *spherical* femoral heads	58	73 4
Patients with *non spherical* femoral heads	21	26 6

Within the group of patients with spherical heads

1

Epiphyseal quotient	No of pts	% of all pts
100–96 incl	2	2 5
100–91 incl	8	10 0
100–86 incl	12	15 2
100–81 incl	21	26 6
100–76 incl	26	33 0
100–71 incl	34	43 0
100–66 incl	42	53 2
100–61 incl	47	59 5
100–56 incl	50	63 3
100–51 incl	55	70 0
100–46 incl	57	72 0
100–41 incl	58	73 4

2

Joint surface quotient	No of pts	% of all pts
110–106 incl	2	2 5
110–101 incl	6	7 6
110– 96 incl	14	17 8
110– 91 incl	38	48 0
110– 86 incl	49	62 0
110– 81 incl	54	68 3
110– 76 incl	57	72 2
110– 71 *incl*	58	73 4

3

Radius quotient	No of pts	% of all pts
100–104 incl	10	12 7
100–109 incl	25	31 6
100–114 incl	40	50 6
100–119 incl	48	61 0
100–124 incl	52	66 0
100–129 incl	54	68 5
100–134 incl	58	73 4

NORM sph 36 pts = 45 6 % PATH sph 22 pts = 27 9 %

(Table 6 continued)

Table 9

♂	A I	A II	A III	B I	B II	B III
Wh series (93 pts.)	12/21	19/40	0/4	4/10	4/16	0/2
BR series (60 pts.)	2/3	11/19	3/8	7/10	6/16	2/4
Tr series (97 pts.)	12/12	25/27	3/14	10/14	14/25	1/5

Diagram 4. J.M.'s measurements

♂+♀	as referred	A I	A II	B I	B II	A III + B III
Wh series	54/114	19/24	22/46	6/13	7/23	0/8
Tr series	75/113	14/14	28/33	13/17	15/29	5/20

Diagram 32. LAU's measurements

♂+♀	as referred	A I	A II	B I	B II	A III + B III
Wh series	57/114	15/20	26/42	9/17	6/27	1/8
Tr series	71/113	10/10	19/23	15/20	20/40	7/20

Diagram 5

♂+♀	as referred	A I	A I II	A II	A II B I	A II B I II	B I-II	A III B I II	A III B I II III	A III B II III
Wh series	54/114	19/24	41/70	22/46	28/59	35/82	13/36	13/40	13/44	7/31
Tr series	75/113	14/14	42/47	28/33	41/50	56/79	28/46	32/61	33/66	20/49

Table 26 Percentages in Tables 1 3 4 5 6 7 8 and 9 and in Diagrams 4 5 and 32 expressed in number of patients

Table 1

Radiological groups	Wh series	BR series	Tr series
NON sph	17/114	21/79	18/113
PATH sph	43/114	22/79	20/113
NORM sph	54/114	36/79	75/113

Table 3

	Age groups		
	I	II	III
Wh series (114 pts)	37/114	69/114	8/114
BR series (79 pts)	17/79	48/79	14/79
Tr series (113 pts)	31/113	62/113	20/113

Table 4

	Stage	
	A	B
Wh series (114 pts)	68/114	46/114
BR series (79 pts)	25/79	54/79
Tr series (113 pts)	45/113	68/113

Table 5

	Sex	
	♂	♀
Wh series (114 pts)	93/114	21/114
BR series (79 pts)	60/79	19/79
Tr series (113 pts.)	97/113	16/113

Table 6

♂+♀	A I	A II	A III	B I	B II	B III
Wh series (114 pts)	24/114	46/114	4/114	13/114	23/114	4/114
BR series (79 pts)	5/79	24/79	10/79	12/79	24/79	4/79
Tr series (113 pts)	14/113	33/113	15/113	17/113	29/113	5/113

Table 7

♂+♀	A I	A II	A III	B I	B II	B III
Wh series (114 pts)	19/24	22/46	0/4	6/13	7/23	0/4
BR series (79 pts)	4/5	13/24	3/10	7/12	7/24	2/4
Tr series (113 pts)	14/14	28/33	4/15	13/17	15/29	1/5

Table 8

♂	A I	A II	A III	B I	B II	B III
Wh series (93 pts)	21/93	40/93	4/93	10/93	16/93	2/93
BR series (60 pts)	3/60	19/60	8/60	10/60	16/60	4/60
Tr series (97 pts)	12/97	27/97	14/97	14/97	25/97	5/97

Table 8 Statistical calculation

Application of the Fisher Yates test (two-tailed)(Geigy Wissenschaftliche Tabellen 7th Ed p 109) showed that

I The frequency of patients with *normally spherical"* heads differed significantly in the	
Tr series and Wh series as referred	$p < 0.01$
Tr series and BR series as referred	$p < 0.01$
A II groups of the Tr series and Wh series	$p < 0.01$
A II groups of the Tr series and BR series	$p < 0.05$
Boys of the A II groups of the Tr series and of the Wh series	$p < 0.001$
Boys of the A II groups of the Tr series and of the BR series	$p < 0.02$
The frequency of patients with *spherical* heads differed significantly in the	
Boys of the A II groups of the Tr series and Wh series	$p < 0.05$
II The frequency of patients with *spherical* heads did *not* differ significantly in the	
Tr series and Wh series as referred	$p > 0.05$
Tr series and BR series as referred	$p > 0.05$
A II groups of the Tr series and of the Wh series	$p > 0.05$
A II groups of the Tr series and of the BR series	$p > 0.05$
Boys of the A II groups of the Tr series and BR series	$p > 0.05$

Whether the different groups of patients are statistically comparable is discussed in the text

Table 27 Survey of radiological results of treatment of all patients – GIRLS + BOYS – in the series as referred and their A II groups and also of BOYS alone in the same series and groups.

Results of treating GIRLS + BOYS in the			No of pts.	% NORM sph	% SPH
	1	Wh series as referred by Wh	114	47 %	85 %
a	2	BR series as referred by BR	79	46	73
	3	Tr series as referred by Tr	113	66	84
	1	A II group of Wh series by Wh	46	48	80
b	2	A II group of BR series by BR	24	54	79
	3	A II group of Tr series by Tr	33	85	97
	1	Wh series as referred by Wh		47	85
c	2	Wh series as referred by BR	114	54	82 calcul
	3	Wh series as referred by Tr		76	91 calcul
	1	BR series as referred by Wh		36	79 calcul
d	2	BR series as referred by BR	79	46	73
	3	BR series as referred by Tr		64	80 calcul
	1	Tr series as referred by Wh		38	82 calcul
e	2	Tr series as referred by BR	113	48	82 calcul
	3	Tr series as referred by Tr		66	84
Results of treating BOYS in the					
	1	Wh series as referred by Wh	93	47 %	82 %
♂a	2	BR series as referred by BR	60	52	77
	3	Tr series as referred by Tr	97	67	84
	1	A II group of Wh series by Wh	40	47	77
♂b	2	A II group of BR series by BR	19	58	84
	3	A II group of Tr series by Tr	27	92	100
	1	Wh series as referred by Wh		47	82
♂c	2	Wh series as referred by BR	93	57	83 calcul
	3	Wh series as referred by Tr		81	93 calcul
	1	BR series as referred by Wh		32	76 calcul
♂d	2	BR series as referred by BR	60	52	77
	3	BR series as referred by Tr		65	83 calcul
	1	Tr series as referred by Wh		35	78 calcul
♂e	2	Tr series as referred by BR	97	53	78 calcul
	3	Tr series as referred by Tr		67	84

1 2 and 3 signify Wh BR and Tr treatment respectively
calcul = the results are calculated

Chart . 19 LCPD series followed up – analysed in the clinical section.
Number of patients and age. Age range chiefly within the limits stated – possibly a few isolated cases outside
I ≤4 years, II = 5–8 years, III – ≥9 years at institution of treatment

Designation of series No. (cf Chart I)	Designation of series Abbrev	No of pts. (or hips)	Age at institution of treatment I II III (cf rad section) % % %	Age at follow-up: Mean age (years)	Age at follow-up: Age range (years)	Age at follow-up: Age distribution ♂ = ♂ of pts in the series
Age group III (40–45 years)						
1	HE.	47	13 – 47 – 40	42	32 – 57	0 % <30 yrs. <89 % <50 yrs. <11 %
2	SU_{II}	63 (69 hips)	15 – 57 – 27	40	32 – 59	ca. 32 yrs. <87 % <47 yrs. <13 %
3	GOW	36	5 – 39 – 56	45	35 – 60	0 % <30 yrs. <78 % <50 yrs. <22 %
4	DA	35	15 – 51 – 34	41	26 – 61	11 % <30 yrs. <69 % <50 yrs. <20 %
5	RAT	34	10 – 60 – 30	38	29 – 52	30 yrs. <90 % <50 yrs.
Age group II (about 20–25 years – 2 series not measured <20 years)						
6	SU_{I}	74 (85 hips)	15 – 57 – 27	ca. 25	(17 – 32)	
7	EV	52	16 – 62 – 22	[illegible]3	15 – 42	
8	STA	132 (146 hips)		ca. 19	(11 – 39)	
9	M & S	72	16 – 65 16	ca. 20	(9 – 39)	
10	EA	88 (100 hips)	9 – 37 – 53	ca 25	(17 – 50)	
11	EV & LLR (in hosp.)	24	25 – 75 – 0	ca 13	(10 – 15)	
12	WA	129	14 – 60 – 26	ca. 20	(15 – 30)	
Age group I (<10 years – all series measured (1 series = 20–21 years))						
13	EB	52	(62 % <8 yrs. <38 %)	ca. 0–21		
14	MO	64	39 – 54 7	<20		
15	BR	79	21 – 61 – 18	12 (1960)	6 – 18	9 yrs. <87 % <16 yrs.
16	KA	229	23 – 69 – 8	<20		
17	STE1	75	30 – 8 22	16 – 20		
18	Wh	114	32 – 61 – 7	13 (1968)	5 – 22	9 yrs. <78 % <16 yrs.
19	Tr	113	27 – 55 – 18	13 (1968)	7 – 21	9 yrs. <75 % <16 yrs.

Chart 1 19 LCPD series followed up – analysed in the clinical section

Age groups III mean age about 40–45 years
II mean age about 20–25 years
I mean age <20 years

Designation of series Numbers and abbreviations of authors names (or treatments) used in the present study
Authors names and year of publication (further information in the list of references)
Nos 15 18 and 19 The three series evaluated in the present study The bed rest (BR) series wheelchair (Wh) series and traction (Tr) series

Age groups	Designation of series		Author – year
	No	Abbreviation	
III	1	HE	Helbo 1953
	2	SU_{II}	Sundt 1949 (pts. followed >25 years)
	3	GOW	Gower & Johnston 1971
	4	DA	Danielsson & Hernborg 1965
	5	RAT	Ratliff 1967
II	6	SU_{I}	Sundt 1949 (pts. followed <25 years)
	7	EV	Evans 1958
	8	STA	Stamp et al 1959
	9	M & S	Mindell & Sherman 1951
	10	EA	Eaton 1967
	11	EV & Ll R	Evans & Lloyd Roberts 1958
	12	WA	Wansbrough et al 1959
I	13	EB	Ebach 1967
	14	MO	Mose 1964 (Thomas splint)
	15	BR	Mose 1964 Meyer 1966
	16	KA	Katz 1967
	17	STEI	Steinhauser 1967
	18	Wh	Lauritzen 1975
	19	Tr	Meyer – present paper

Chart 4 19 LCPD series followed up – analysed in the clinical section.

Classifications *Age groups II and III The various authors classifications. The classifications are based upon an estimate – mainly according to radiological criteria. In 2 series (5 and 8) however the criteria were radiological-clinical*

Age group I In this age group the classifications were based upon the result of radiological measurements using the nomenclature of the present study (cf text p 20)

Age group	Series No	Classifications of the series	
III	1	spherical 12 % – greatly flattened 61 % – irregular 27 %	
	2	spherical 9 % – ovoid 36 % – cylindrical 52 % – angular 3 %	
	3	round 20 % – flattened 73 % – angular 7 %	
	4	0 17 % – 1 23 % – 2 23 % – 3 37 %	
	5	good 44 % – fair 32 % – poor 23 % (cf Appendix Comment 3)	
II	6	spherical 6 % – o oid 37 % – cylindrical 48 % – angular 8 %	
	7	good 29 % – fair 40 % – poor 31 %	
	8	satisfactory 38 % – fair 25 % – poor 37 %	
	9	satisfactory 56 % – fair 15 % – poor 29 %	
	10	spherical 7 % – mildly flattened 55 % – moderately flattened 19 % – severely flattened 19 %	
	11	almost normal 62 % – intermediate 21 % – bad 17 %	
	12	excellent 35 % – good 29 % – fair 21 % – poor 15 %	
I	13	NORM sph " (E) 47 % – "PATH sph " (E) 13 % – "NON sph 40 %	("SPH 60 %)
	14	"NORM sph (E) 42 % – PATH sph " (E) 19 % – "NON-sph " 39 %	(" SPH " 61 %)
	15	NORM sph 46 % – PATH sph " 27 % – NON sph 27 %	("SPH " 73 %)
	16	NORM sph " (E) 68 % – "PATH.sph (E) 12 % – "NON sph " 20 %	("SPH " 80 %)
	17	"NORM sph " (E) 71 % – PATH sph " (E) 11 % – NON sph " 18 %	(" SPH " 82 %)
	18	NORM sph. 47 % – PATH sph " 38 % – NON sph " 15 %	("SPH." 85 %)
	19	"NORM sph 66 % – "PATH sph 18 % – NON-sph 16 %	("SPH " 84 %)

Chart 3 19 LCPD series followed up – analysed in the clinical section
Treatment *by non weightbearing*

No	Author etc (cf Chart 1)	NON WEIGHTBEARING % of the pts in the series	Duration (years)	In hospital/At home	No non weightbearing % of the pts in the series
Age group III (40–45 years)					
1	HE	(60) only symptomatic	<3/12		(40)
2	SU_{II}	(40) only symptomatic	mean 6/12		(60)
3	GOW	30	mean 8/12	chiefly at home	70
4	DA	95	mean 6/12	in hosp	5
5	RAT	75	mean 18/12	in hosp	25
Age group II (20–25 years)					
6	SU_I	(40) only symptomatic	mean 6/12		(60)
7	EV	100	25/12	in hosp	0
8	STA	68	mean 27/12	in hosp /at home	32
9	M & S	82	1–2	in hosp /at home	18
10	EA	80	>6/12	chiefly in hosp	20
11	EV & LIR (in hosp)	100	25/12	in hosp	0
12	WA	100	1–2	chiefly at home	0
Age group I (<20 years – at primary healing)					
13	EB	100	34/12	chiefly at home	0
14	MO	100	ca 22/12	at home	0
15	BR	100	24/12	in hosp 18/12	0
16	KA	100	long lasting		0
17	STEI	100	15/12	at home	0
18	Wh	100	1–2	at home	0
19	Tr	100	24/12	in hosp 18/12	0

Table 9 Primary radiological deformity radiological osteoarthritis and subjective clinical symptoms in 19 LCPD series.

Age group	Series No	Primary radiol deformity: NORM sph % of all pts.	Primary radiol deformity: SPH % of all pts.	Radiol osteoarthritis: Spread over % of the series (cf diagr)	Radiol osteoarthritis: % of pts. without spread	Radiol osteoarthritis: % of pts. with narrowing of joint space	Subjective clinical sympt (Cause Primary radiol. deformity or radiol osteoarthritis): Spread over % of the series (cf diagr)	Subjective clinical sympt: % of pts. without spread	Subjective clinical sympt: % of pts. with disabling osteoarthr
		%	%	%	%	%	%	%	%
III	1		12	88	56		88	62	21
	2		27	91	58		91	68	19
	3		30	86	77	42	86	61	27
	4		35	72	50	28	37	23 (0)	?
	5		48	55	50	25	23	20	10
II	6		24	76	32		57	29	6
	7		49	31	?		80	37	10
	8		50				62	?	
	9		64	29	?		44	?	
	10		64	19	?		63	48	6
	11		73						
	12		76	15			36	?	6
I	13		60				53	32	
	14		61				?	?	
	15	46	73				60	22	
	16		80				?	?	
	17		82				29	11	
	18	47	85				?	?	
	19	66	84				40	13	

Chart 5 19 LPCD series followed up

Age group	Series No	% SPH estimated by J M or measured % of series	Age groups III and II Pt groups in the authors classification comprised by the group SPH as estimated by J M Age group I Group SPH directly measured
III	1	12 ?	spherical
	2	27	spherical + ½ ovoid
	3	30	round + 10 % flattened
	4	35	0 + ¾ 1
	5	48	good + 4 % (cf Appendix Comment 3)
II	6	24 ?	spherical + ½ ovoid
	7	49	good + ½ fair
	8	50	satisfactory + ½ fair
	9	64	satisfactory + ½ fair
	10	64	spherical + mildly flattened
	11	73	almost normal + ½ intermediate
	12	76	excellent + good + ½ fair
I	13	60 ?	direct measurement
	14	61	direct measurement
	15	73	direct measurement
	16	80	direct measurement
	17	82	NORM sph (L) + 11 %
	18	85	direct measurement
	19	84	direct measurement

Table 9 Primary radiological deformity radiological osteoarthritis and subjective clinical symptoms in 19 LCPD series.

		Primary radiol deformity		Radiol. osteoarthritis			Subjective clinical sympt. (Cause Primary radiol deformity or radiol osteoarthritis)		
Age group	Series No	"NORM sph." % of all pts.	SPH" % of all pts	Spread over % of the series (cf diagr)	% of pts. without spread	% of pts. with narrowing of joint space	Spread over % of the series (cf diagr)	% of pts. without spread	% of pts. with disabling osteoarthr
		%	%	%	%	%	%	%	%
III	1		12	88	56		88	62	21
	2		27	91	58		91	68	19
	3		30	86	77	42	86	61	27
	4		35	72	50	28	37	23 (20)	?
	5		48	55	50	25	23	20	10
II	6		24	76	32		57	29	6
	7		49	31	?		80	37	10
	8		50				62	?	
	9		64	29	?		44	?	
	10		64	19	?		63	48	6
	11		73						
	12		76	15	?		36	?	6
I	13		60				53	32	
	14		61				?	?	
	15	46	73				60	22	
	16		80				?	?	
	17		82				29	11	
	18	47	85				?	?	
	19	66	84				40	13	

Table 30 Development of osteoarthritis in Ruelle's total material of secondary osteoarthritis (pt groups I and II a total of 271 pts)

Among 271 pts with sec osteoarthr who applied for treatment in a rheumat clinic *the symptoms of osteoarthritis started*							Total survey % of all clin cases of osteoarthr developing before the ages stated	
In age group	No of pts	Before age	In No *of pts*	% of 271 found	Before age	% of 271 calculated (interpolation)	Age	% osteo arthritis
years	No	years	No	%	years	%	years	%
		80	271	100			80	100
70 – 80	3				75	99 5	75	99 5
		70	268	99			70	99
60 – 70	17				65	96	65	96
		60	251	93			60	93
50 – 60	61				55	81	55	81
		50	190	70			50	70
40 – 50	93				45	53	45	53
		40	97	36			40	36
30 – 40	69				35	23	35	23
		30	28	10			30	10
20 – 30	(22) (graphic)				25	(3) (graphic)	25	(3) (graphic)
		20	(6) (graphic)	(2) (graphic)			20	(2) (graphic)
10 – 20	(6) (graphic)							
		10	0					

PATIENT LISTS

The patient lists for the traction and bed rest series comprise all patients referred for LCPD to the Seaside Hospital Refsnæs during the periods 1958–63 and 1953–57 respectively

All figures on the lists refer to unilateral cases on which the evaluation was based The remainder – the majority bilateral – are only marked Excl (excluded) adding the reason for exclusion

The patients of the wheelchair series are arranged in the same way – only 17 patients from the study period (1957–64 incl) are missing as they were excluded before J M got the opportunity to see the series Nearly all these cases were bilateral

The number of the patients of the 3 series treated for LCPD is then

	Number of pts.	% of all treated cases
Unilateral cases		
Wheelchair series	114	
Bed rest series	79	
Traction series	113	
Bilateral cases		
Wheelchair series	21	15 6 %
Bed rest series	14	15 1
Traction series	24	17 5

(As to the justification of excluding bilateral cases in the evaluation of the therapeutic results cf Meyer 1966)

Table 31 Number of patients with dysplasia of the capital femoral epiphysis (J.M 1964) *(this number can only be approximate as the limit between dysplasia and typical LCPD is not sharp)*

Wheelchair series	Unilateral dysplasia about 12/144 = 10.5 %.
Bed rest series	Unilateral dysplasia. The number is not definitely known as the series was measured before the syndrome dysplasia was described (Meyer 1964) (No >3/79 (3 8 %)).
Traction series	Unilateral dysplasia about 10/113 8 8 % unilateral + bilateral 19/137 = 13 6 %.

Table 30 Development of osteoarthritis in Ruelle s total material of secondary osteoarthritis (pt groups I and II a total of 271 pts)

Among 271 pts with sec osteoarthr who applied for treatment in a rheumat clinic *the symptoms of osteoarthritis started*							*To [illegible]* % of all clin cases of osteoarthr developing before the ages stated	
In age group	No of pts	Before age	In No of pts	% of 271 found	Before age	% of 271 calculated (interpolation)	Age	% osteoarthritis
years	No	years	No	%	years	%	years	%
		80	271	100			80	100
70 – 80	3				75	99 5	75	99 5
		70	268	99			70	99
60 – 70	17				65	96	65	96
		60	251	93			60	93
50 – 60	61				55	81	55	81
		50	190	70			50	70
40 – 50	93				45	53	45	53
		40	97	36			40	36
30 – 40	69				35	23	35	23
		30	28	10			30	10
20 – 30	(22) (graphic)				25	(3) (graphic)	25	(3) (graphic)
		20	(6) (graphic)	(2) (graphic)			20	(2) (graphic)
10 – 20	(6) (graphic)							
		10	0					

No	Sex	Condition at institution of treatment			Radiological result			
		Stage/ initial quotient	Age at inst. of treatment (years)	Brief designation	Ep quot	It surf quot	Ra quot.	Group
1		Excl – bilat.						
2		Excl – quest path.						
3	♂	Co – 91	7	A II	82 –	88 –	109	"NORM sph"
4	♀	Fragm	4	B I	41 –	74 –	122	"PATH sph."
5	♂	Co – 94	7	A II	83 –	105 –	110	NORM sph."
6	♂	Co – 100	5	A II	91 –	100 –	100	"NORM sph"
7	♂	Co – 103	6	A II	58 –	93 –	130	"PATH sph"
8	♂	Dy – 100	3	A I	94 –	96 –	100	"NORM sph"
9		Excl quest path						
10	♂	Co – 97	2	A I	94 –	100 –	100	"NORM sph"
11	♂	Co – 103	5	A II	97 –	104 –	100	"NORM sph"
12	♂	Co 89	6	A II	"NON-sph"			"NON-sph."
13	♂	Fragm	6	B II	53 –	94 –	122	"PATH sph"
14	♂	Co 91	5	A II	48 –	78 –	136	"PATH sph."
15	♂	Co – 77	6	B II	71 –	87 –	116	"PATH sph."
16	♂	Co – 79	11	B III	86 –	84 –	107	"PATH sph."
17	♂	Dy 100	5	A II	94 –	103 –	105	"NORM sph"
18	♂	Co 104	6	A II	84 –	81 –	110	PATH sph.
19	♂	Co 96	5	A II	39 –	91 –	1 5	PATH sph
20		Excl – bilat						
21	♂	Co 43	4	B I	55 –	92 –	108	"PATH sph"
22	♂	Dy 93	3	A I	93 –	103 –	105	NORM sph"
23	♀	Fragm	6	B II	46 –	75 –	135	PATH sph"
24	♂	Co 100	4	A I	39 –	8[illegible] –	150	PATH sph"
25	♂	Fragm	4	B I	61 –	78 –	134	PATH sph"
26	♂	Fragm	3	B I	74 –	109 –	100	NORM sph"
27	♂	Dy 86	4	A I	87 –	96 –	100	NORM sph"
28	♂	Co 83	4	B I	61 –	85 –	118	PATH sph"
29		Excl bilat						
30	♂	Co 89	4	A I	68 –	100 –	100	NORM sph"
31		Excl bilat						
32	♂	Co 94	8	A II	74 –	101 –	109	NORM sph"
33	♂	Co 75	7	B II	89 –	88 –	109	NORM sph"
34	♂	Co 88	5	A II	61 –	85 –	111	"PATH sph"
35	♀	Co 91	3	A I	87	99 –	106	"NORM sph"
36	♂	Co 80	5	B II	44 –	66 –	155	"PATH sph"
37	♂	Co 87	3	A I	83 –	91 –	100	"NORM sph"
38	♂	Co 76	7	B II	43 –	98 –	118	"PATH sph"
39	♀	Fragm	5	B II	79 –	91 –	110	"NORM sph"
40	♂	Co 95	2	A I	55	75 –	133	"PATH sph"
41	♂	Co 107	4	A I	100 –	95 –	107	"NORM sph"
42	♂	Co 97	8	A II	"NON sph"			"NON-sph"
43	♂	Co 96	6	A II	64 –	103 –	110	"NORM sph"
44	♂	Dy 100	6	A II	85	84 –	110	"PATH sph"
45	♀	Co 84	10	B III	65	83 –	1 5	"PATH sph"
46	♂	Co 93	11	A III	64 –	77 –	115	PATH sph."
47	♂	Co 86	8	A II	66	93 –	108	"NORM sph"
48	♂	Co 75	3	B I	71 –	100 –	100	"NORM sph"

Table 32 Wheelchair series – corresponding numbers
Transfer table between J M s pt Nos in the present study and LAU s pt Nos in his thesis from 1975 (Excluded pts not listed)

J M No	LAU No	J M No	LAU No	J M No	LAU No	J M No	LAU No	J M No	LAU No	J M No	LAU No
3	108	25	82	47	67	69	35	89	3	109	123
4	126	26	88	48	85	70	33	90	2	110	118
5	128	27	94	49	87	71	31	91	100	111	107
6	138	28	102	50	101	72	29	92	30	112	86
7	127	30	110	53	91	73	28	93	20	113	76
8	139	32	113	54	84	74	141	94	90	114	75
10	106	33	115	55	63	75	122	95	16	116	68
11	120	34	116	56	61	76	83	96	7	117	65
12	114	35	119	57	58	77	70	97	9	118	62
13	111	36	117	58	53	78	54	98	36	119	46
14	104	37	124	59	52	79	34	99	66	120	44
15	95	38	125	60	51	80	26	100	56	122	39
16	79	39	130	61	50	81	23	101	78	123	11
17	72	40	129	62	48	82	22	102	27	124	5
18	71	41	132	63	47	83	21	103	92		
19	57	42	133	64	49	84	18	104	17		
21	41	43	134	65	43	85	69	105	10		
22	103	44	137	66	42	86	14	106	6		
23	80	45	136	67	45	87	12	107	4		
24	81	46	64	68	38	88	8	108	1		

Abbreviations and terms used in the patient lists

Excl — Excluded (reason stated)
Co — Stage of condensation
Fragm — Stage of fragmentation
A — Stage of condensation Initial quotient >85
B — Stage of condensation Initial quotient <85
Bilat — Bilateral
I — Age ⩽4 years
II — Age 5–8 years
III — Age ⩾9 years
Dy — Dysplasia of the capital femoral epiphysis
NORM sph — Cases healed with spherical heads of normal shape and size
PATH sph — Cases healed with spherical heads of pathological shape and/or size
NON sph — Cases healed with heads without circular contours

No	Sex	Condition at institution of treatment			Radiological result			
		Stage/ initial quotient	Age at inst of treatment (years)	Brief desig nation	Ep quot	Jt surf quot	Ra. quot	Group
97	♂	Co – 81	7	B II	62 –	87 –	124	"PATH sph "
98	♂	Co – 86	7	A II	91 –	97 –	100	"NORM sph "
99	♂	Co – 95	3	A I		NON sph "		"NON-sph
100	♂	Co – 103	7	A II	84 –	93 –	108	"NORM sph "
101	♀	Fragm	7	B II	65 –	75 –	133	"PATH sph "
102	♂	Co – 105	10	A III		NON-sph "		"NON-sph "
103	♂	Co – 80	6	B II	31 –	75 –	132	"PATH sph "
104	♂	Co – 90	4	A I	90 –	87 –	100	"NORM sph "
105	♂	Co – 81	7	B II		"NON-sph "		"NON sph "
106	♂	Co – 103	6	A II	75 –	82 –	113	"PATH sph "
107	♂	Co – 56	3	B I	53 –	90 –	120	"PATH sph "
108	♂	Co – 87	4	A I	69 –	92 –	109	"NORM sph "
109	♂	Co – 99	8	A II		"NON sph "		"NON sph.
110	♂	Co – 92	8	A II	75 –	83 –	110	"PATH sph
111	♂	Co – >85	6	A II	85 –	89 –	112	"NORM sph "
112	♂	Co – 103	8	A II		"NON sph "		NON-sph
113	♂	Co – 105	6	A II	58 –	90 –	116	"PATH sph.
114	♂	Co – 119	7	A II	72 –	102 –	107	NORM sph "
115		Excl – not tr here						
116	♀	Co – 100	6	A II	100 –	103 –	100	"NORM sph "
117	♂	Co – 89	7	A II		NON sph "		NON-sph "
118	♂	Fragm	5	B II	73 –	93 –	107	"NORM sph."
119	♀	Fragm	7	B II	63 –	95 –	109	"NORM sph "
1 0	♂	Co – 94	5	A II	43 –	74 –	138	"PATH sph "
121		Excl. – bilat.						
122	♂	Dy – 86	2	A I	96 –	96 –	104	NORM sph "
121	♂	Co – 95	3	A I	77 –	90 –	108	"NORM sph
1 4	♂	Dy – 105	3	A I	100 –	96 –	100	"NORM sph "

(17 excluded patients not listed here)

Bed rest series. Measurements J M

No	Sex	Stage/ initial quotient		Age	Brief desig nation	Ep quot	Jt surf quot	Ra. quot	Group
1		Excl	bilat						
2	♂	Fragm		7	B II	82 –	95 –	109	"NORM sph "
3	♀	Co	92	9	A III		NON-sph "		"NON sph "
4	♂	Co	78	3	B I	95	94 –	100	"NORM ph."
5		Excl	not tr here						
6		Ex l.	bilat						
7	♂	Co	78	6	B II		"NON-sph.		"NON-sph "
8	♀	Co	72	6	B II	46 –	78 –	127	"PATH sph."
9	♀	Co	78	6	B II	55 –	91	117	"PATH sph "
10	♂	Co	89	6	A II	78 –	103 –	108	"NORM sph."
11	♀	Fragm		6	B II	58	92 –	109	"PATH sph."
12	♂	Dy	8	7	B II	83	96 –	109	NORM sph "
13		Ex l.	bilat						
14	♂	Co	102	7	A II	70	95 –	108	"NORM sph."
15	♂	Fragm.		4	B I	83 –	93 –	100	NORM.sph

No	Sex	Condition at institution of treatment			Radiological result			
		Stage/ initial quotient	Age at inst of treatment (years)	Brief designation	Ep quot	Jt surf quot	Ra quot	Group
49	♀	Dy – 100	5	A II	97 –	96 –	104	NORM sph
50	♂	Co – 107	6	A II	75 –	98 –	110	NORM sph
51		Excl – Ep lysis						
52		Excl – cong disloc						
53	♂	Co – 100	3	A I	78 –	109 –	100	NORM sph
54	♂	Co – 91	3	A I	90 –	96 –	100	NORM sph
55	♂	Co – 100	6	A II	67 –	93 –	108	NORM sph
56	♂	Co – 93	6	A II	68 –	98 –	113	NORM sph
57	♂	Co – 103	7	A II	76 –	92 –	109	NORM sph
58	♂	Fragm	8	B II	70 –	90 –	105	NORM sph
59	♂	Co – 92	8	A II	88 –	82 –	122	PATH sph
60	♂	Co – 87	5	A II		NON sph		NON sph
61	♀	Co – 104	4	A I	76 –	78 –	122	PATH sph
62	♀	Dy – 67	2	B I	80 –	95 –	106	NORM sph
63	♀	Fragm	6	B II	41 –	79 –	120	PATH sph
64	♂	Co – 55	4	B I		NON sph		NON sph
65	♂	Fragm	6	B II	59 –	96 –	105	PATH sph
66	♂	Co – 79	6	B II	91 –	95 –	105	NORM sph
67	♀	Co – 82	6	B II	70 –	87 –	105	NORM sph
68	♂	Fragm	6	B II	53 –	87 –	116	PATH sph
69	♀	Co – 91	6	A II	54 –	90 –	117	PATH sph
70	♂	Fragm	10	B III	68 –	89 –	115	PATH sph
71	♀	Fragm	9	B III		NON sph		NON sph
72	♂	Co – 74	6	B II	58 –	91 –	107	PATH sph
73	♂	Dy – 106	2	A I	79 –	95 –	105	NORM sph
74	♂	Co – 89	5	A II		NON sph		NON sph
75	♀	Fragm	8	B II		NON sph		NON sph
76	♂	Co – 90	3	A I		NON sph		NON sph
77	♂	Co – 104	4	A I	90 –	100 –	100	NORM sph
78	♂	Co – 59	4	B I	67 –	87 –	128	PATH sph
79	♀	Fragm	4	B I	69 –	88 –	100	NORM sph
80	♂	Co – 100	6	A II	86 –	102 –	92	NORM sph
81	♂	Fragm	7	B II	40 –	92 –	128	PATH sph
82	♀	Co – 92	5	A II	74 –	105 –	104	NORM sph
83	♂	Co – 92	11	A III		NON sph		NON sph
84	♂	Co – 110	5	A II	93 –	85 –	100	PATH sph
85	♂	Co – 69	3	B I	77 –	94 –	111	NORM sph
86	♂	Co – 103	6	A II		NON sph		NON sph
87	♀	Co – 117	6	A II	67 –	90 –	117	PATH sph
88	♂	Fragm	8	B II	52 –	88 –	118	PATH sph
89	♂	Co – 75	1	B I	78	90 –	111	NORM sph
90	♂	Co – 107	9	A III	65 –	88 –	118	PATH sph
91	♂	Co – 95	5	A II	94 –	92 –	105	NORM sph
92	♂	Co – 97	7	A II		NON sph		NON sph
93	♂	Co – 92	6	A II	61 –	91 –	118	PATH sph
94	♂	Co – 91	3	A I	71 –	90 –	111	NORM sph
95	♀	Dy – 91	3	A I	62 –	90 –	111	NORM sph
96	♀	Co – 87	5	A II	81 –	94 –	100	NORM sph

Mecklur series. – Measurements, J.M

No	Sex	Condition at institution of treatment: Stage/initial quotient	Age at inst. of treatment (years)	Brief desig nation	Radiological result: Ep quot	Jt surf quot	Ra. quot	Group
97	♂	Co – 81	7	B II	62 –	87 –	124	"PATH sph"
98	♂	Co – 86	7	A II	91 –	97 –	100	NORM sph"
99	♂	Co – 95	3	A I		NON sph		"NON sph
100	♂	Co – 103	7	A II	84 –	93 –	108	NORM sph"
101	♀	Fragm	7	B II	65 –	75 –	133	PATH sph
102	♂	Co – 105	10	A III		NON-sph		"NON-sph"
103	♂	Co – 80	6	B II	31 –	75 –	132	'PATH sph
104	♂	Co – 90	4	A I	90 –	87 –	100	NORM sph"
105	♂	Co – 81	7	B II		NON sph.		NON-sph
106	♂	Co – 103	6	A II	75 –	82 –	113	"PATH sph"
107	♂	Co – 56	3	B I	53 –	90 –	120	'PATH sph"
108	♂	Co – 87	4	A I	69 –	92 –	109	NORM sph"
109	♂	Co – 99	8	A II		"NON sph"		"NON-sph"
110	♂	Co – 92	8	A II	75 –	83 –	110	"PATH sph"
111	♂	Co – >85	6	A II	85 –	89 –	112	"NORM sph"
112	♂	Co – 103	8	A II		"NON sph		"NON-sph"
113	♂	Co – 105	6	A II	58 –	90 –	116	'PATH sph
114	♂	Co – 119	7	A II	72 –	102 –	107	"NORM.sph"
115		Excl. – not tr here						
116	♀	Co – 100	6	A II	100 –	103 –	100	"NORM sph"
117	♂	Co – 89	7	A II		NON sph"		"NON-sph"
118	♂	Fragm	5	B II	73 –	93 –	107	NORM sph
119	♀	Fragm	7	B II	63 –	95 –	109	"NORM.sph"
120	♂	Co – 94	5	A II	43 –	74 –	138	"PATH sph"
121		Excl. – bilat.						
122	♂	Dy – 86	2	A I	96 –	96 –	104	"NORM sph"
123	♂	Co – 95	3	A I	77 –	90 –	108	'NORM sph
124	♂	Dy – 105	3	A I	100 –	96 –	100	'NORM sph

(17 excluded patients not listed here)

Bed rest series. Measurements J.M

No	Sex	Stage/initial quotient	Age at inst. of treatment (years)	Brief desig nation	Ep quot	Jt surf quot	Ra. quot	Group
1		Excl bilat						
2	♂	Fragm	7	B II	82 –	95	109	"NORM sph"
3	♀	Co – 92	9	A III		"NON sph"		"NON-sph"
4	♂	Co 78	3	B I	95	94 –	100	"NORM sph"
5		Ex l not tr here						
6		Excl. bilat.						
7	♂	Co 78	6	B II		"NON-sph		"NON-sph."
8	♀	Co 72	6	B II	46 –	78 –	127	"PATH sph."
9	♀	Co 78	6	B II	55	91	117	"PATH sph.
10	♂	Co 83	6	A II	78	103	108	"NORM sph."
11	♀	Fragm	6	B II	58	97	109	"PATH sph."
12	♂	Dy 8	7	B II	83	96	109	"NORM sph."
13		Ex L bilat.						
14	♂	Co 10	7	A II	70	95	108	"NORM sph"
15	♂	Fragm.	4	B I	83	93 –	100	"NORM.sph."

No	Sex	Condition at institution of treatment			Radiological result			
		Stage/ initial quotient	Age at inst of treatment (years)	Brief designation	Ep quot	Jt surf quot	Ra quot	Group
16	♂	Fragm	6	B II		NON sph		NON sph
17	♀	Co – 78	6	B II	71 –	94 –	110	NORM sph
18		Excl – bilat						
19	♂	Co – 103	8	A II	68 –	92 –	109	NORM sph
20	♂	Co – 98	5	A II	45 –	78 –	133	PATH sph
21	♂	Co – 84	5	B II		NON sph		NON sph
22	♂	Co – 89	10	A III		NON sph		NON sph
23	♀	Co – 92	7	A II		NON sph		NON sph
24	♂	Co – 72	6	B II	66 –	93 –	105	NORM sph
25		Excl – bilat						
26	♂	Co – 91	7	A II	78 –	92 –	109	NORM ph
27	♀	Co – 90	8	A II		NON sph		NON ph
28	♂	Co – 100	5	A II	92 –	107 –	100	NORM ph
29	♂	Co – 96	11	A III	67 –	82 –	116	PATH sph
30	♂	Co – 79	4	B I	73 –	90 –	111	NORM sph
31		Excl – not tr here						
32	♂	Co – 80	3	B I	65 –	105 –	100	NORM sph
33	o	Fragm	8	B II	63 –	90 –	114	NORM sph
34	♂	Dy – 70	3	B I	88 –	87 –	100	NORM sph
35	♀	Fragm	8	B II		NON sph		NON ph
36	♂	Co – 107	7	A II	100 –	100 –	100	NORM sph
37	♂	Co – 94	3	A I	71 –	87 –	110	NORM sph
38	♂	Co – 104	4	A I	89 –	105 –	100	NORM sph
39	♀	Fragm	7	B II		NON sph		NON sph
40	♀	Co – 90	4	A I	84 –	92 –	108	NORM sph
41	♂	Co – 99	9	A III	98 –	97 –	100	NORM sph
42	♂	Co – 108	7	A II	93 –	95 –	110	NORM sph
43	♂	Co – 82	6	B II		NON sph		NON sph
44		Excl – bilat						
45	♂	Co – 87	9	A III		NON sph		NON sph
46		Excl – not tr here						
47		Excl – bilat						
48		Excl – bilat						
49	♂	Co – 107	11	A III		NON sph		NON sph
50	♀	Co – 92	8	A II	62 –	91 –	117	PATH sph
51	♂	Co – 100	7	A II	59 –	87 –	133	PATH sph
52	♂	Fragm	7	B II		NON sph		NON sph
53		Excl – bilat						
54	♂	Co – 100	6	A II	68 –	92	109	NORM ph
55	♂	Co – 89	6	A II	81	93	122	PATH sph
56	♂	Fragm	4	B I	78 –	86	111	NORM ph
57	♂	Fragm	6	B II	86 –	92	109	NORM sph
58	♂	Co 98	10	A III	68 –	96	104	NORM ph
59		Excl – bilat						
60	♂	Co – 98	10	A III	61 –	96	111	NORM ph
61		Excl – bilat						
62	♂	Co 103	6	A II		NON sph		NON sph
63	♂	Co – 98	7	A II		NON sph		NON sph

Bed rest series – Measurements J.M

No	Sex	Condition at institution of treatment: Stage/initial quotient	Age at inst of treatment (years)	Brief desig nation	Radiological result: Ep quot	Jt surf quot	Ra quot	Group
64	♂	Fragm	3	B I	84 –	95 –	110	"NORM sph
65	♂	Co – 75	8	B II		NON-sph"		NON sph
66	♂	Co – 106	8	A II	93 –	102 –	108	NORM sph"
67	♀	Fragm	8	B II		NON sph"		NON ph"
68	♀	Co – 93	9	A III		"NON-sph		NON sph"
69	♂	Co – 86	7	A II		NON sph		NON sph
0		Excl. – bilat						
71	♀	Co – 83	4	B I	48 –	78 –	118	'PATH sph"
72	♂	Co – 88	5	A II	77 –	92 –	108	"NORM sph
73	♂	Fragm	7	B II	71 –	86 –	108	"NORM sph"
74		Excl. – bilat						
75	♂	Fragm	9	B III	83 –	100 –	104	"NORM sph"
76	♂	Co – 83	4	B I	72 –	87 –	120	'PATH sph
77	♂	Fragm	7	B II	71 –	83 –	133	'PATH sph"
78	♀	Fragm	5	B II	52 –	87 –	130	"PATH sph
9	♂	Fragm	14	B III		NON sph		"NON-sph"
80	♀	Co – >85	5	A II	67 –	94 –	110	'NORM sph"
81	♂	Co – 62	6	B II	51	72 –	127	"PATH sph"
82	♂	Co – 91	4	A I	71	81 –	111	"PATH sph
83	♂	Co – 100	7	A II	83 –	85 –	114	'PATH sph"
84	♂	Co 69	5	B II		NON-sph"		"NON-sph."
85	♂	Co – 87	4	A I	72 –	89 –	112	NORM sph
86	♂	Co 97	6	A II	84 –	106 –	116	'PATH sph"
87	♂	Co 93	9	A III	87	91 –	118	"PATH sph
88	♂	Fragm	3	B I	58 –	97 –	120	"PATH sph"
89	♂	Co 94	8	A II	79 –	98 –	110	"NORM sph"
90		Excl. – bilat						
91	♂	Fragm	13	B III	64 –	84 –	115	"PATH sph"
92	♂	Fragm	10	B III	93 –	94 –	107	"NORM sph"
93	♀	Fragm	4	B I	54 –	87 –	110	"PATH sph"
94	♂	Co 92	6	A II	95 –	93 –	111	"NORM sph"
95	♂	Co 84	8	B II	70 –	92 –	117	PATH sph
96	♂	Fragm	4	B I	53 –	92 –	122	"PATH sph

T action series   Measurements J.M

No	Sex	Stage/initial quotient		Age at inst of treatment (years)	Brief desig nation	Ep quot	Jt surf quot	Ra quot	Group
1	♂	Co	100	8	A II	82 –	91 –	103	NORM sph"
2	♂	Co	75	6	B II	85	92 –	109	NORM sph
3	♀	Co	88	11	A III	96 –	94 –	104	"NORM sph"
4	♂	Co	103	9	A III	66 –	86 –	120	PATH sph"
5		Ex l	b lat						
6	♂	Co	100	5	A II	88 –	100 –	100	"NORM sph"
7	♂	Co	83	5	B II	72 –	100 –	100	"NORM sph"
8	♂	Fragm		9	B III	79 –	96	104	"NORM sph"
9	♂	Co	88	8	A II	84	99 –	104	NORM sph
10	♂	Co	81	9	B III		NON-sph.		"NON sph"
11	♂	Co	91	4	A I	83 –	93 –	96	"NORM sph"
12	♂	Co	100	6	A II	84 –	93 –	104	NORM sph"

No	Sex	Condition at institution of treatment			Radiological result			
		Stage/ initial quotient	Age at inst of treatment (years)	Brief desig nation	Ep quot	Jt surf quot	Ra quot	Group
16	♂	Fragm	6	B II		NON sph		NON sph
17	♀	Co – 78	6	B II	71	94	110	NORM sph
18		Excl – bilat						
19	♂	Co – 103	8	A II	68	92	109	NORM sph
20	♂	Co – 98	5	A II	45	78	133	PATH sph
21	♂	Co – 84	5	B II		NON sph		NON sph
22	♂	Co – 89	10	A III		NON sph		NON sph
23	♀	Co – 92	7	A II		NON sph		NON sph
24	♂	Co – 72	6	B II	66	93	105	NORM sph
25		Excl – bilat						
26	♂	Co – 91	7	A II	78	92	109	NORM sph
27	♀	Co – 90	8	A II		NON sph		NON sph
28	♂	Co – 100	5	A II	92	107	100	NORM sph
29	♂	Co – 96	11	A III	67	82	116	PATH sph
30	♂	Co – 79	4	B I	73	90	111	NORM sph
31		Excl – not tr here						
32	♂	Co – 80	3	B I	65	105	100	NORM sph
33	♂	Fragm	8	B II	63	90	114	NORM sph
34	♂	Dy – 70	3	B I	88	87	100	NORM sph
35	♀	Fragm	8	B II		NON sph		NON sph
36	♂	Co – 107	7	A II	100	100	100	NORM sph
37	♂	Co – 94	3	A I	71	87	110	NORM sph
38	♂	Co – 104	4	A I	89	105	100	NORM sph
39	♀	Fragm	7	B II		NON sph		NON sph
40	♀	Co – 90	4	A I	84	92	108	NORM sph
41	♂	Co – 99	9	A III	98	97	100	NORM sph
42	♂	Co – 108	7	A II	93	95	110	NORM sph
43	♂	Co – 82	6	B II		NON sph		NON sph
44		Excl – bilat						
45	♂	Co – 87	9	A III		NON sph		NON sph
46		Excl – not tr here						
47		Excl – bilat						
48		Excl – bilat						
49	♂	Co – 107	11	A III		NON sph		NON sph
50	♀	Co – 92	8	A II	62	91	117	PATH sph
51	♂	Co – 100	7	A II	59	87	133	PATH sph
52	♂	Fragm	7	B II		NON sph		NON sph
53		Excl – bilat						
54	♂	Co – 100	6	A II	68	92	109	NORM sph
55	♂	Co – 89	6	A II	81	93	122	PATH sph
56	♂	Fragm	4	B I	78	86	111	NORM sph
57	♂	Fragm	6	B II	86	92	109	NORM sph
58	♂	Co – 98	10	A III	68	96	104	NORM sph
59		Excl – bilat						
60	♂	Co – 98	10	A III	61	96	111	NORM sph
61		Excl – bilat						
62	♂	Co – 103	6	A II		NON sph		NON sph
63	♂	Co – 98	7	A II		NON sph		NON sph

Bad res series. – Measurements J M

No	Sex	Condition at institution of treatment: Stage/initial quotient	Age at inst. of treatment (years)	Brief desig nation	Radiological result: Ep quot	Jt surf quot	Ra quot.	Group
64	♂	Fragm	3	B I	84 –	95 –	110	NORM sph."
65	♂	Co – 75	8	B II		NON-sph "		NON-sph "
66	♂	Co – 106	8	A II	93 –	102	108	"NORM sph "
67	♀	Fragm	8	B II		NON-sph "		"NON-sph "
68	♀	Co 93	9	A III		"NON-sph		"NON sph "
69	♂	Co – 86	7	A II		NON-sph		NON sph."
70		Excl. – bilat						
71	♀	Co – 83	4	B I	48	78 –	118	"PATH.sph "
72	♂	Co – 88	5	A II	77 –	92	108	"NORM sph "
73	♂	Fragm	7	B II	71 –	86 –	108	"NORM sph "
74		Excl. – bilat						
75	♂	Fragm	9	B III	83 –	100 –	104	NORM sph."
76	♂	Co – 83	4	B I	72 –	87 –	120	"PATH sph "
77	♂	Fragm	7	B II	71 –	83 –	133	"PATH sph."
78	♀	Fragm	5	B II	52 –	87 –	130	"PATH sph "
79	♂	Fragm	14	B III		NON-sph		"NON-sph "
80	♀	Co – >85	5	A II	67 –	94 –	110	"NORM sph "
81	♂	Co – 62	6	B II	51	72 –	127	"PATH sph
82	♂	Co – 91	4	A I	71	81 –	111	"PATH sph "
83	♂	Co – 100	7	A II	83	85 –	114	"PATH sph "
84	♂	Co – 69	5	B II		"NON sph "		"NON-sph "
85	♂	Co – 87	4	A I	72 –	89	112	"NORM sph
86	♂	Co – 97	6	A II	84 –	106 –	116	"PATH sph
87	♂	Co – 93	9	A III	87 –	91 –	118	"PATH sph "
88	♂	Fragm	3	B I	58 –	97 –	120	"PATH sph "
89	♂	Co – 94	8	A II	79 –	98 –	110	"NORM sph "
90		Excl – bilat						
91	♂	Fragm	13	B III	64 –	84 –	115	PATH sph "
92	♂	Fragm	10	B III	93 –	94 –	107	"NORM sph "
93	♀	Fragm	4	B I	54	87 –	110	"PATH sph "
94	♂	Co – 92	6	A II	95 –	93 –	111	"NORM sph "
95	♂	Co – 84	8	B II	70 –	92 –	117	"PATH sph "
96	♂	Fragm	4	B I	53 –	92 –	122	"PATH sph

Favourable series. Measurements J M

No	Sex	Stage/initial quotient	Age	Brief desig nation	Ep quot	Jt surf quot	Ra quot.	Group
1	♂	Co – 100	8	A II	82	91 –	103	NORM sph "
2	♂	Co 75	6	B II	85	92	109	NORM sph "
3	♀	Co 88	11	A III	96	94	104	NORM sph "
4	♂	Co 103	9	A III	66 –	86	1 0	PATH sph
5		Excl bilat						
6	♂	Co 100						
7	♂	Co 83	5	A II	88 –	100	100	"NORM sph "
8	♂	Fragm	5	B II	7	100	100	NORM sph "
9	♂	Co 88	9	B III	79	96	104	"NORM sph "
10	♂	Co 87	8	A II	84	99	104	"NORM sph "
11	♂	Co 91	9	B III		NON ph		NON sph
12	♂	Co – 100	4	A I	83	93	96	"NORM sph
			6	A II	84	93 –	104	"NORM sph "

No	Sex	Condition at institution of treatment				Radiological result			
		Stage/ initial quotient	Age at inst of treatment (years)	Brief desig nation		Ep quot	Jt surf quot	Ra. quot	Group
13	♂	Co – 87	5	A II		86	94	103	NORM sph
14	♂	Co – 74	6	B II		68	82	122	PATH sph
15	♂	Co – 97	6	A II		86	96	108	NORM sph
16	♂	Fragm	7	B II		55	86	117	PATH sph
17		Excl – bilat							
18	♂	Fragm	4	B I		59	90	108	PATH sph
19		Excl – not tr here							
20	♀	Co –	6	B II		NON sph			NON sph
21	♂	Co –	10	A III		78	90	115	PATH sph
22	♂	Co – 85	5	B II		59	96	104	PATH sph
23		Excl – bilat							
24		Excl – other diagn							
25	♀	Co – 88	8	A II		70	71	119	PATH sph
26	♂	Co – 93	7	A II		82	91	103	NORM sph
27	♂	Co – 92	4	A I		97	100	100	NORM sph
28	♂	Co – 87	11	A III		84	95	103	NORM sph
29	♂	Co – 87	9	A III		58	74	125	PATH sph
30	♂	Dy – 71	5	B II		95	100	100	NORM sph
31		Excl – not tr here							
32		Excl – doublet							
33		Excl – bilat							
34	♂	Co – 96	5	A II		94	100	100	NORM sph
35	♂	Co – 93	7	A II		87	97	107	NORM sph
36		Excl – not tr here							
37	♀	Co – 96	4	A I		100	100	100	NORM sph
38		Excl – treatm interrupt							
39	♂	Dy – 84	4	B I		113	107	100	NORM sph
40	♂	Co – 95	12	A III		NON sph			NON sph
41	♂	Co – 76	6	B II		77	96	104	NORM sph
42	♀	Co – 104	4	A I		85	96	100	NORM sph
43	♀	Co – 60	4	B I		91	96	104	NORM sph
44	♀	Fragm	3	B I		78	107	100	NORM sph
45	♂	Co – 87	5	A II		91	92	104	NORM sph
46	♂	Co – 98	12	A III		NON sph			NON sph
47	♀	Co – 60	6	B II		NON sph			NON sph
48	♂	Co – 100	9	A III		86	94	100	NORM sph "
49	♂	Co – 72	7	B II		NON sph			NON sph
50	♂	Co – 89	5	A II		88	93	100	NORM sph
51	♂	Co – 89	8	A II		91	88	104	NORM sph
52	♂	Co – 81	6	B II		84	100	100	NORM sph
53	♂	Fragm	5	B II		75	100	104	NORM sph
54		Excl – bilat							
55		Excl – bilat							
56	♂	Co – 71	4	B I		79	88	100	NORM sph "
57	♂	Co – 83	4	B I		71	89	104	NORM sph "
58		Excl – bilat							
59	♂	Fragm	6	B II		51	88	119	PATH sph
60	♂	Co – 50	7	B II		NON sph			NON sph

No	Sex	Condition at institution of treatment: Stage/initial quotient	Age at inst of treatment (years)	Brief desig nation	Radiological result: Ep quot	Jt surf quot.	Ra quot	Group
61	♂	Co – 93	4	A I	86 –	92 –	100	"NORM sph"
62		Excl. – bilat.						
63	♂	Co – 90	5	A II	79 –	92 –	105	"NORM sph"
64	♂	Dy – 69	3	B I	84 –	100 –	100	"NORM sph"
65	♂	Co – 101	6	A II	82 –	99 –	105	"NORM sph"
66	♂	Co – 89	9	A III	NON sph"			"NON-sph"
67	♂	Co – 100	3	A I	88 –	101 –	96	NORM sph"
68	♂	Fragm	6	B I	82 –	85 –	105	"PATH sph"
69	♂	Co – 73	3	B I	79 –	104 –	105	"NORM sph"
70		Excl. – not tr here						
71		Excl. – bilat.						
72	♂	Dy – 58	2	B I	76 –	75 –	128	PATH sph"
73	♂	Co – 78	6	B II	88 –	95 –	105	"NORM sph"
74	♂	Co – 92	6	A II	75 –	89 –	117	"PATH sph"
75	♂	Dy – 96	3	A I	100 –	95 –	105	"NORM sph"
76	♂	Co 93	9	A III	"NON-sph"			"NON-sph."
77	♂	Co 100	10	A III	"NON sph			"NON-sph"
78	♂	Dy – 88	3	A I	94 –	100 –	100	"NORM sph."
79	♂	Co 95	4	A I	94 –	101 –	96	"NORM sph"
80	♂	Co 110	7	A II	41 –	82 –	125	"PATH sph
81	♂	Fragm	7	B II	58 –	88 –	118	"PATH sph
82	♂	Co – 89	4	A I	83 –	86 –	113	"NORM sph"
83	♂	Dy 75	3	B I	92 –	91 –	106	"NORM sph"
84	♂	Co 78	8	B II	66 –	84 –	130	"PATH sph
85		Excl b lat						
86		Excl. bilat						
87	♂	Fragm	3	B I	74 –	94 –	107	"NORM sph"
88		Excl. not tr here						
89	♀	Co 100	7	A II	93 –	78 –	116	"PATH sph"
90	♂	Co 100	10	A III	"NON sph"			"NON-sph."
91		Excl Coxitis						
92	♂	Co 91	9	A III	NON-sph."			"NON-sph"
93	♂	Co 90	6	A II	87 –	103 –	104	"NORM sph"
94	♂	Co 78	5	B II	67 –	85 –	114	"PATH sph"
95	♂	Fragm	11	B III	NON sph"			"NON-sph"
96	♂	Dy >85	2	A I	75	90	106	"NORM sph"
97	♀	Co 86	8	A II	80 –	91 –	104	"NORM sph."
98	♀	Co 85	6	B II	86 –	96 –	104	"NORM sph"
99	♂	Fragm	5	B II	88 –	99 –	105	"NORM sph"
100		Excl. bilat						
101	♂	Co 96	4	A I	94 –	96 –	100	"NORM sph."
102	♂	Co 67	3	B I	79	87 –	110	"NORM sph"
103		Excl bilat						
104	♂	Co >85	6	A II	84 –	96 –	104	"NORM sph"
105		Excl. bilat.						
106		Excl. bilat						
107		Excl. not tr here						
108	♂	Fragm	11	B III	"NON-sph"			"NON-sph."

No	Sex	Condition at institution of treatment			Radiological result			
		Stage/ initial quotient	Age at inst of treatment (years)	Brief designation	Ep quot	Jt surf quot	Ra quot	Group
109	♂	Co – 103	5	A II	85 –	82 –	109	NORM sph
110		Excl – bilat						
111	♂	Co – 101	4	A I	97 –	99 –	104	NORM sph
112	♂	Fragm	9	*B III*		*NON sph*		*NON sph*
113		Excl – not tr here						
114	♂	Co – 92	5	A II	91 –	88 –	109	NORM sph
115		Excl – not tr here						
116	♂	Co – 80	4	B I	75 –	92 –	109	NORM sph
117	♀	Co – 83	3	B I	103 –	104 –	100	NORM sph
118	♂	Co – 98	9	A III	91 –	88 –	107	NORM sph
119	♂	Fragm	8	B II	75 –	88 –	114	NORM sph
120	♂	Co – 99	6	A II	111 –	96 –	104	NORM sph
121	♂	Co – 94	9	A III		NON sph		NON sph
122		Excl – bilat						
123	♂	Co – 67	8	*B II*	*74* –	*103* –	*111*	NORM sph
124		Excl – bilat						
125	♀	Co – 88	8	A II	83 –	89 –	108	NORM sph
126		Excl – bilat						
127	♂	Fragm	6	B II		NON sph		NON sph
128	♂	Fragm	7	B II	64 –	92 –	127	PATH sph
129		Excl – bilat						
130		Excl – cong disloc						
131		Excl – bilat						
132		Excl – not tr here						
133		Excl – bilat						
134	♂	*Co* – 94	7	A II	84 –	92 –	109	NORM sph
135		Excl – not tr here						
136	♂	Co – 97	6	A II	100 –	97 –	100	NORM sph
137		Excl – Error diagn (normal)						
138	♀	Co – 97	8	A II		NON sph		NON sph
139	♂	Fragm	4	B II	76 –	86 –	122	PATH sph
140		Excl – bilat						
141	♂	Co 100	4	A I	79 –	99 –	111	NORM sph
142	♂	Dy – 83	2	B I	88 –	100 –	105	NORM sph
143		Excl – cong disloc						
144	♂	Co – 100	5	A II	98 –	100 –	100	NORM sph
145		Excl – bilat						
146	♂	Fragm	8	B II	73 –	92 –	109	NORM sph
147	♀	Co – 98	5	A II	91 –	94 –	111	NORM sph
148	♂	Co – 86	6	A II	80 –	92 –	104	NORM sph
149	♂	Fragm	5	B II	75 –	104 –	109	NORM sph
150	♀	Fragm	5	B II	59 –	79 –	122	PATH sph
151		*Excl* – cong disloc						
152	♂	Fragm	5	B II	81 –	92 –	104	NORM sph
153	♂	Co 91	5	A II	92 –	100 –	100	NORM sph "
154	♂	Fragm	8	B II	90 –	103 –	104	NORM sph
155		Excl – bilat						
156	♂	Co – 92	5	A II	75 –	90 –	111	NORM sph

REFERENCES

Axer A et al (1973) *Acta orthop scand.* 44 31

Catterall A (1971) *J Bone Jt Surg.* 53 B No 3 37

Catterall A (1972) *Modern Trends in Orthopaedics* – 6 127 London

Danielsson L G (1964) Incidence & Prognosis of Coxarthrosis *Acta orthop scand.* Suppl 66

Danielsson L G & Hernborg J (1965) *Acta orthop scand.* 36 70

Duverney (1956) Gruber Duverney & Francois Francon *Documenta rheumatologica GEIGY* Basle

Eaton G O (1957) *J Bone Jt Surg* 48 A 1031

Ebach G (1968) *Verhandlungen d Deutschen orthop Ges* 54 Kongr 198

Evans D L (1958) *J Bone Jt Surg.* 40 B 168

Evans D L & Lloyd Roberts G C (1958) *J Bone Jt Surg* 40 B 182

Fauconnet M & Vignon C (1968) *Lyon medical* 219 No ? 1171

Francon F (1959) Osteoarthritis of the Hip *Documenta rheumatolog GEIGY* No 9

Goff C W (1954) *Legg Calve-Perthes Syndrome and Related Osteochondrosis of Youth.* Thomas Springfield

Gower W E & Johnston R C (1971) *J Bone Jt Surg.* 53 A 759

Iversen Sven (1953) *Morbus Calve Perthes,* Odense

Jeffery A K (1973) *J Bone Jt Surg* 55 B No 2 6?

Jequier M & Streiff E B (1947) *Archiv d Julius Klaus Stiftung* Bd XXII 129 Zurich

Jerre T (1950) A Study in Slipped Upper Femoral Epiphysis *Acta orthop scand.* Suppl 6

Katz J F (1967) *J Bone Jt Surg.* 49 A 1043

Lance M (1937) in Ombrédanne & Mathieu Traité d chir orthop. Tome IV 3180 Paris

Lauritzen Jorgen (1975) Legg Calvé Perthes Disease *Acta orthop scand.* Suppl 159

Lloyd Roberts G C (1955) *J Bone Jt Surg* 37 B 1 8

Mau H. (1958) *Wesen und Bedeutung der enchondrale Dysostosen.* Stuttgart

Meyer Johannes (1964) *Acta orthop scand* 34 183

Meyer Johannes (1966) Treatment of Legg Calvé Perthes Disease *Acta orthop scand* Suppl 86

Meyer Johannes (1969) *Medicinsk Årbog* XII København

Mindell E R & Sherman M S (1951) *J Bone Jt Surg* 33 A 1

Mose K (1964) *Legg Calve-Perthes Disease* Thesis Aarhus

Moller P Flemming (1924) *Malum deformans coxae infantile.* København

Newman P H (1963) *J Bone Jt Surg* 45 B 39

Nielasen S Dahl (1974) *Annales societatis scient Færoensis.* Torshavn

Ratliff A H C (1956) *J Bone Jt Surg* 38 B 498

Ratliff A H C (1967) *J Bone Jt Surg* 49 B 102

Ruelle M (1961) *Journ. Belge d med. physique et d. Rheumatologie* 16 No 3 113

Stamp W G Canales G Odell R T (1959) *J A M A* 169 1443

Steinhauser E (1970) *Z f Orthop* 107 4 558

Sundt Halfdan (1920) *Undersogelser over Malum coxae Calve-Legg-Perthes.* Oslo

Sundt Halfdan (1949) Malum coxae Calvé Legg Perthes *Acta chir scand.* Suppl 148

Thomasen E (1969) *Orthopædisk kirurgi" Lærebog for sygeplejeelever* p 24 b Copenhagen

Thomasen E (1969) *Acta orthop scand.* 10 331

Wansbrough R M Carrie A W Walker N F & Ruckerbauer G (1959) *J Bone Jt Surg.* 41 A 135

Wiberg G (1939) Studies on Dysplastic Acetabula and Congenital Subluxation of the Hip Joint *Acta chir scand.* Suppl 58

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KAREL BJORN CYVIN

A Follow-up Study of Children with Instability of the Hip Joint at Birth

Clinical and Radiological Investigations with Special Reference to the Anteversion of the Femoral Neck

Acta Orthopaedica

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From the Pediatric Clinic, Regional Hospital of Trondheim, Norway

A Follow-up Study of Children with Instability of the Hip Joint at Birth

Clinical and Radiological Investigations with Special Reference to the Anteversion of the femoral neck

BY

KAREL BJORN CYVIN

MUNKSGAARD COPENHAGEN

To My Wife Helga

CONTENTS

INTRODUCTION

Since the pioneer works of Le Damany (1908) and Ortolani (1937) the modern principles of early diagnosis and treatment of congenital dislocation of the hip (CDH) have been gradually adopted in most countries. The earliest reports of the clinical aspects of the disease are from Russia (Marx 1938), USA (Chapple 1935, Hart 1948), Czechoslovakia (Frejka 1941) and Austria (von Haberler 1944). Investigations on CDH in Sweden have been carried on since 1950 (Palmen 1950, 1957, 1961, 1970, von Rosen 1970, Andrén 1960, Palmén & von Rosen 1975). In Norway important contributions to the subject have been made by Walter & Moe (1954), Njå (1962), Medbøe (1961, 1965) and Bjerkreim (1974). To-day newborn babies in most countries are routinely examined by the classical manoeuvre ("signe de ressault") by which instability of the hip joint can be revealed and infants with dislocated or dislocatable hips are generally treated with an abduction splint.

The results of the early treatment of unstable hips have been the subject of great interest in medical literature. The most optimistic investigators claim that all or nearly all cases of CDH can be diagnosed in the newborn period and that with correct treatment these children will develop normal hips (Palmén 1961, von Rosen 1970, Fredensborg 1976 a.o.). On the other hand many of the follow up studies include groups of patients in whom apparently correct therapy has failed (Finlay 1967, James et al 1960, Mitchell 1972 a.o.). Finally a minor group of authors have presented rather discouraging results of early therapy (Weissmann 1968, Ackermann 1974, Bjerkreim 1974). None has as yet given a satisfactory explanation for the divergent therapeutic results of early treatment of unstable hips.

Reviewing the extensive literature on the results of early treatment of CDH I was impressed by the following facts: 1. None of the follow up studies include control groups of children from the same population matched with the patients for sex and age. 2. Few of the clinical and radiological studies present results which allow definite conclusions of possible "minor" abnormalities of the hip joint. Such abnormalities may pass without obvious symptoms during childhood and adolescence, but may well be the cause of development of arthritic changes of the adult hip. Among such abnormalities increased anteversion of the femoral neck represents a major problem. Despite numerous investigations on that topic the true nature of the condition is still obscure.

The main aims of the following investigation were:

1. A detailed follow up study of children with unstable hips at birth treated with an abduction splint, in comparison with a control group of presumably healthy children, and a third group of children with unstable hips at birth but untreated.

2. An evaluation of "minor" pathological findings, with special attention paid to increased anteversion of the femoral neck.

PATIENTS AND METHODS

During the period 1. 5. 1969–1. 5. 1971 6509 children (3322 boys and 3187 girls) were born in the two maternity units in Trondheim (E. C. Dahls Stiftelse and the Ob-

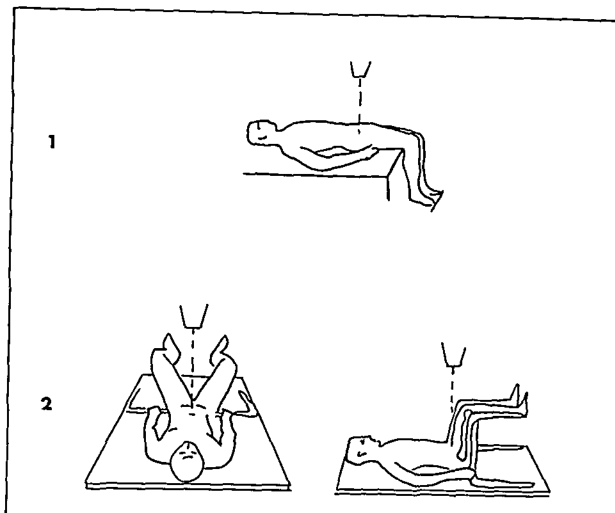


Figure 1 The radiographic examination of the hip joint according to Dunlap and Rippstein 1 An anterior posterior view of the pelvis 2 The position in Müller s apparatus

stetrical Department of the Regional Hospital of Trondheim) Most of the mothers came from the city of Trondheim whereas a smaller group came from the neighbouring communities The newborns were examined at least twice the first examination being performed on the first or second day of life and the second generally four to six days after birth About 6000 children were examined by me the rest by one of the trained consultants of the pediatric department The hips of the newborns were examined according to Palméns and Barlows modification of the Ortolani test (Palmén 1957 Barlow 1962)

In the course of the two years period instability of the hip joint was found in 146 children, 115 girls and 31 boys One child with arthrogryposis was excluded from the material The instability of the hip joint was right sided only in 38 (26 per cent) left sided only in 61 (42 per cent) and bilateral in 47 (32 per cent) Breech presentation occurred in 30 children (20 6 per cent)

Table 1 Examination of children with unstable hips at birth and control children with stable hips at the age of four to six years

Group	No	Findings at birth	Treatment
A	129	unstable hips	Frejkas pillow
B	100	stable hips	none
C	17	unstable hips	none

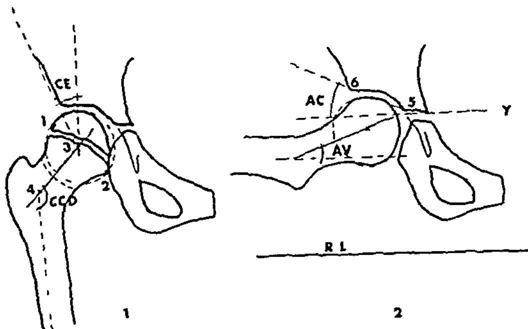


Figure 2 The radiographic measurements of the hip joint 1 The first X ray picture Wibergs angle (CE) and neck shaft angle (CCD) 2 The second X ray picture inclination of the acetabular roof (AC) and torsion (anteversion) of the femoral neck (AV)

All the children with unstable hips were treated in Frejkas cushion splint usually for three months The patients were checked by me at three months six months and fourteen months of age They were radiographed on the last two controls Standardization of the radiological method of these controls was not adequate to make the results suitable for scientific presentation The aim of these controls was primarily to disclose clearly pathological conditions

The control group of children consisted of subjects of the same sex and born chronologically next to the children with unstable hips These children received no treatment

A clinical and radiological follow up study was performed at four to six years of age The follow up study comprised three groups of children (Table 1)

Group A consisted of 129 children (103 girls and 26 boys) with unstable hips at birth treated with Frejkas pillow Of the originally total number 146 fifteen patients had moved from the town and were unavailable for the examination

In seven patients of group A (No 20 54 61 78 93 99 and 140 the course of the disease was unfavourable and these patients needed additional treatment at the Orthopedic department with splinting or plaster cast In two of them (No 78 and No 140) a derotational osteotomy was performed

Group B consisted of 100 healthy children (80 girls and 20 boys)

Group C comprised 17 children (12 girls and 5 boys) born at the Maternity Hospital of Haukeland Hospital in Bergen In those infants instability of the hip joint was diagnosed at birth but all of them had stable joints on the day of discharge from the maternity ward and no treatment was instituted The diagnosis was made by an experienced pedi

Table 2 The range of passive movement of the hip joint at the age of three months in patients with unstable hips at birth

Range in degrees	Hips 90 flexed						Hips extended	
	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40			3	3 6				
40–59	11	13 3	46	55 4			17	22 0
60–79	30	36 1	9	10 8			59	76 7
80–90	42	50 6	25	30 1	81	97 6	1	1 3
asymmetrical	0	0 0			2	2 4	0	0 0
Total	83		83		83		77	

Table 3 The range of passive movements of the hip at the age of five to ten months in patients with unstable hips at birth

Range in degrees	Hips 90 flexed						Hips extended	
	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40								
40–59	22	23 4	1		2	2 1	1	
60–79	47	50 0	5	5 3	24	25 5	39	45 4
80–90	24	25 5	88	93 6	65	69 1	46	53 5
asymmetrical	1		0		3	3 3	0	
Total	94		94		94		86	

Table 4 The range of passive movement of the hip at the age of twelve to twenty one months in patients with unstable hips at birth

Range in degrees	Hips 90 flexed						Hips extended	
	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40	1							
40–59	14	15 7			3	3 4	2	
60–79	49	55 0	16	18 0	23	25 8	49	55 0
80–90	25	28 0	73	82 0	61	69 0	38	42 7
asymmetrical	0		0		2	2 5	0	
Total	89		89		89		89	

atrician and he also followed the children in several controls up to the age of eighteen months

All the clinical examinations of the follow up study were performed by me The following data were recorded 1 Observations made by the parents such as limping stumbling asymmetry of the extremities in toeing when walking and subjective symptoms of the child such as fatigue or muscular pain in the extremities 2 Objective examinations shortening and/or atrophy of the lower extremities, Trendelenburg s sign, observation

of the gait evaluation of the muscular strength and measurements of the range of passive movement Flexion and abduction were measured in the supine position extension internal and external rotation were measured in the prone position In addition abduction and internal and external rotation were measured in the supine position with hips and knees at right angles This was mainly performed in order to be able to compare measurements with those of the newborn children who have a marked *flexion contracture*

Table 5 The development of walking of children with unstable hips at birth

Age of walking without support in months	No	%
9 12	27	37 5
13 15	34	47.2
16 19	11	15.3
Total	2	100 0

The children were radiographed by specially trained assistants and I participated in most of the examinations The radiographic examination was performed according to Rippsteins modification of the method of Dunlap (*Dunlap et al* 1953 Rippstein 1955) Two exposures were made (Figure 1) 1 An anterior posterior view of the pelvis and the hips *with the patient in the supine position* hips extended thighs parallel and knees flexed 90 over the edge of the table 2 The child placed on a simple apparatus constructed by Muller (Muller 1970) which holds the knees and hips flexed at 90 and thighs abducted 20 The first exposure required 100 mA at 60 kV in 1.2 sec the second 30 mA at 75 kV in 0 3 sec

All the measurements of the radiographs (*Figure 2*) were performed by means of Mullers *ischiometer* (Muller 1970) On the first x ray picture I measured the *neck shaft* angle (CCD) Wibergs angle (CE) which is the angle between a vertical line through the femoral head and a line from the center of the head to the lateral border of the acetabular roof and the length and width of the ossified part of the femoral head The lateral margin of the acetabulum was evaluated and other pathological findings recorded (fragmentation *of* the epiphysis ossification defects subluxations or luxations) On the second picture I measured the anteversion of the femoral neck (AV angle) and the angle of *inclination of the acetabular roof* (AC) All measurements were made twice and the *difference* between the two values *never exceeded* 5 usually it was only 0–2

Corrected values of the CCD and AV angles were computed from the following trigonometric formulas

(I) $tg\,AV = tg\,AV \times$ [cos (CCD 90 γ) − cos (CCD − 90)]
(II) cot CCD = cot CCD × cos AV

Table 6 Development of the femoral epiphyses of children with unstable hips at birth.

Side	Retarded development at	Side affected at birth right	left	bilateral	Total
	right	9	1	5	15
	left		12	2	14
	bilateral	1	3	3	7
	Total	10	16	10	36

Table 2 The range of passive movement of the hip joint at the age of three months in patients with unstable hips at birth

Range in degrees	Hips 90 flexed						Hips extended	
	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40			3	3 6				
40–59	11	13 3	46	55 4			17	22 0
60–79	30	36 1	9	10 8			59	76 7
80–90	42	50 6	25	30 1	81	97 6	1	1 3
asymmetrical	0	0 0			2	2 4	0	0 0
Total	83		83		83		77	

Table 3 The range of passive movements of the hip at the age of five to ten months in patients with unstable hips at birth

Range in degrees	Hips 90 flexed						Hips extended	
	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40								
40–59	22	23 4	1		2	2 1	1	
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asymmetrical	1		0		3	3 3	0	
Total	94		94		94		86	

Table 4 The range of passive movement of the hip at the age of twelve to twenty one months in patients with unstable hips at birth

Range in degrees	Hips 90 flexed						Hips extended	
	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40	1							
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Total	72	100 0

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$[\cos(CCD \quad 90-\gamma) - \cos(CCD - 90)]$
(II) $\cot CCD = \cot CCD \times \cos AV$

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	No	%	No	%	No	%	No	%
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80–90	42	50 6	25	30 1	81	97 6	1	1 3
asymmetrical	0	0 0			2	2 4	0	0 0
Total	83		83		83		77	

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	Internal rotation		External rotation		Abduction		Abduction	
	No	%	No	%	No	%	No	%
< 40								
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60–79	47	50 0	5	5 3	24	25 5	39	45 4
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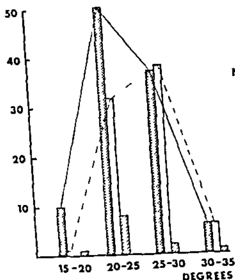
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< 40	1							
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asymmetrical	0		0		2	2 5	0	
Total	89		89		89		89	

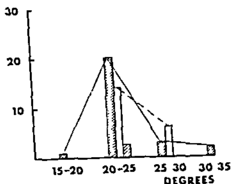
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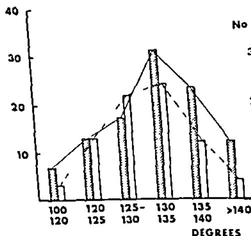
Treated 129 SUBJ
Controls 100
Untreated 17

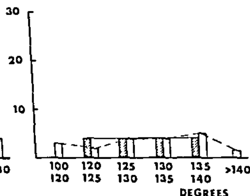
EXTENSION OF THE HIP JOINT





FLEXION OF THE HIP JOINT





F gur 3 The range of passive extension and passive flexion in 129 children with unstable hips at birth treat d w th Frejkas pillow 100 healthy children and 17 children with unstable hips at birth untreated

where CCD denotes the projected CCD angle, AV the projected AV angle CCD the real neck-shaft angle AV the real angle of anteversion and γ the angle of abduction of the hip (here 20°)

Table 7 Radiological signs of dysplasia in children with unstable hips at birth

Signs	Age in months 6–12	13–21
Sloping of the acetabular roof or indistinctly marked lateral margin	12	4
Anteversion of the femoral neck	3	3

The collected data were processed in a UNIVAC 1108 at the Computing Centre of the University of Trondheim The mean values of groups A B and C were computed Differences of means were tested by the t-test, and P values below 0 05 were regarded as statistically significant When indicated regression curves and confidence limits were computed Correlation coefficient > 0 75 was regarded as positive

RESULTS

1 The motor development of children with unstable hips at birth

Of the 146 children with unstable hips at birth 83 were examined at three months of age Results of the examination are shown in Table 2 In nearly all children the range of passive abduction with hips 90 flexed was 80–90°

Ninety-four children were examined at the age of five to ten months (Table 3) At this age the group of children with maximal abduction capacity was reduced to nearly 70 per cent

The results of the clinical examination of 89 children over one year of age are shown in Table 4 27 children were

Table 8 Symptoms and signs of children with unstable hips at birth (Group A) and healthy children (Group B)

Symptoms and signs	Group A No	Group A %	Group B No	Group B %
In toeing when walking	22	17 0	5	5 0
Stumbling	11	8 5	0	0 0
Fatigue	9	7 0	2	2 0
Muscular pain	5	3 9	2	2 0
Limping	0	0 0	0	0 0
General joint laxity	3		1	
Total no	129		100	

Table 9 The passive flexion of 490 hip joints at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys No	Boys Degrees	Boys S D	Girls No	Girls Degrees	Girls S D
A	26	128 46	4 64	103	129 27	7 65
B	20	128 00	8 01	79	127 91	6 49
C	5	129 00	4 18	12	126 67	5 37

Table 10 The passive extension of 490 hip joints at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls		
	No	Degrees	S D	No	Degrees	S D
A	26	21 15	3 [illegible]6	103	21 89	3 71
B	20	21 50	2 35	79	23 10	3 23
C	5	20 00	0 00	12	21 25	3 77

Table 11 The passive abduction of 490 hip joints in extension at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips at birth untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	47 31	4 [illegible]0	103	45 73	5 30	45 97	4 59
B	20	44 50	3 94	79	46 46	3 [illegible]9	46 46	3 59
C	5	45 00	3 54	12	43 33	4 44	43 33	4 44

Table 12 The passive adduction of 490 hip joints at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	23 08	6 49	103	22 48	3 63	22 48	3 63
B	20	22 50	2 [illegible]6	79	22 15	3 07	22 50	2 61
C	5	[illegible]00	[illegible] 74	12	2[illegible] 50	2 61	22 50	2 61

Table 13 The passive abduction of 490 hip joints in 90 flexion at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	53 85	4 54	103	53 45	6 08	53 69	6.89
B	[illegible]0	54	4 06	[illegible]9	55.38	4 44	55.32	4 48
C	5	54 00	[illegible] 24	1[illegible]	51 25	5 69	51 25	5 69

unstable hips at birth is shown in Table 6 It can be seen that in 67 per cent of the cases retardation of the ossification process appeared on the same side as the instability of the hip joint at birth whereas in the rest there was no correlation between the retarded ossification and the instability of the hips

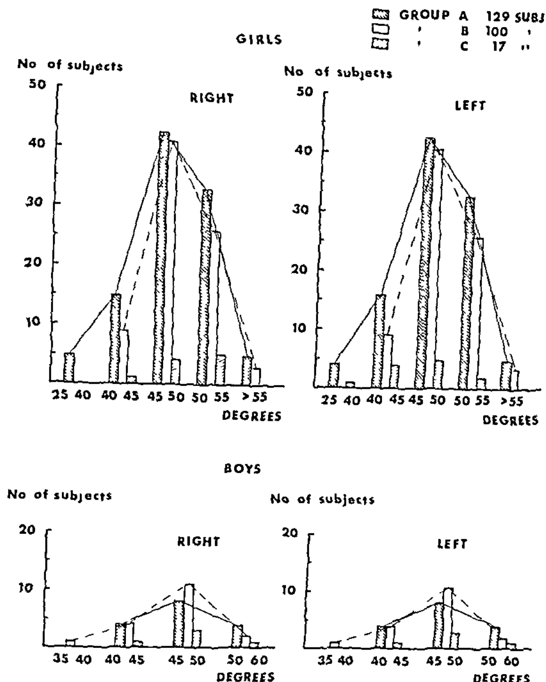


Figure 4 The range of passive abduction with extended hips in 129 children with unstable hips at birth treated with Frejkas pillow 100 healthy children and 17 children with unstable hips at birth untreated

examined at the age of 12-14 months 46 at 15–17 months and 16 at 18–21 months The maximal abduction capacity was practically unaltered compared with the previous examination

Table 5 shows the development of walking As can be seen nearly 50 per cent of the children started to walk without support between 13 and 15 months

2 *The radiological findings during infancy*

The development of the ossification of the femoral epiphysis in 36 children with

Table 10 The passive extension of 490 hip joints at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 39 healthy children (Group B) and 17 children with unstable hips untreated Group C)

Group	Boys			Girls		
	No	Degrees	S D	No	Degrees	S D
A	26	21 15	3 96	103	21 89	3 71
B	20	21 50	2 35	79	23 10	3 23
C	5	20 00	0 00	12	21 25	3 77

Table 11 The passive abduction of 490 hip joints in extension at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 39 healthy children (Group B) and 17 children with unstable hips at birth untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	47.31	4 0	103	45 13	5 30	45 97	4 59
B	20	44 50	3 94	79	46 46	3 59	46 46	3 59
C	5	45 00	3 44	12	43.33	4 44	43.33	4 44

Table 12 The passive adduction of 490 hip joints at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 39 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	23 08	2 49	103	22 48	3 63	22 48	3 63
B	20	22 50	2 56	79	22 15	3 07	22.50	2 61
C	5	22 00	2 74	12	22 50	2 61	22 50	2 61

Table 13 The passive abduction of 490 hip joints in 90 flexion at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 39 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	53 85	4 54	103	53 45	8 08	53 69	6 89
B	20	54 25	4 06	79	55.38	4 44	55.32	4 48
C	5	54 00	2.24	12	51 25	5 69	51 25	5 69

unstable hips at birth is shown in Table 6 It can be seen that in 67 per cent of the cases retardation of the ossification process appeared on the same side as the instability of the hip joint at birth whereas in the rest there was no correlation between the retarded ossification and the instability of the hips

Table 14 The passive internal rotation of 490 hip joints in supine position and 90 flexion of the hips at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	54.42	7.39	103	60.53	10.05	60.87	10.37
B	20	50.50	7.93	79	56.65	7.46	56.56	7.46
C	5	55.00	6.12	12	57.08	7.22	57.08	7.[illegible]2

Table 15 The passive external rotation of 490 hip joints in supine position and 90 flexion of the hips at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	55.28	6.31	103	56.12	8.[illegible]4	56.26	8.[illegible]9
B	20	54.50	3.59	79	54.30	5.[illegible]3	54.30	5.[illegible]3
C	5	49.00	4.18	12	55.00	7.69	55.00	7.69

Table 16 The passive internal rotation of 490 hip joints in prone position at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	26	57.31	8.86	103	64.37	10.0[illegible]	64.76	10.3[illegible]
B	20	54.00	7.71	79	58.71	7.8[illegible]	58.80	7.81
C	5	56.00	6.52	12	61.25	9.56	61.25	9.56

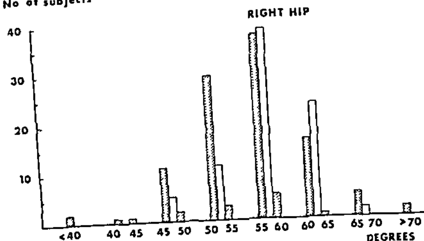
Table 7 shows the frequency of radiological findings described as dysplasia by different radiologists

3 *Results of the clinical examination at 4–6 years of age*

The data regarding the further motor development of the children of group A and group B are based on information from the parents (Table 8) It can be seen that the frequency of abnormalities was higher in group A than in group B The most frequent observation in both groups was in toeing when walking In group A the in toeing could be seen at clinical examination in 6 children in group B in two children

Among the patients of group A six presented symptoms of complicating abnormality or disease Four of them (No 31 71 777 and 119) are described in detail in Case Histories One girl (No 17) had signs of rheumatoid arthritis with a relative shortening of the right lower extremity of 8 mm One boy (No 109) had bilateral pes equinovarus

GROUP A PAT TREATED 103
B CONTROLS 80
C PAT UNTREATED 12
TOTAL No 195



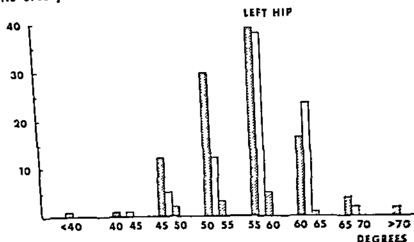


Figure The range of passive abduction with hips 90° flexed in 103 girls with unstable hips at birth treated with Frejka's pillow, 80 healthy girls and 12 girls with unstable hips at birth untreated

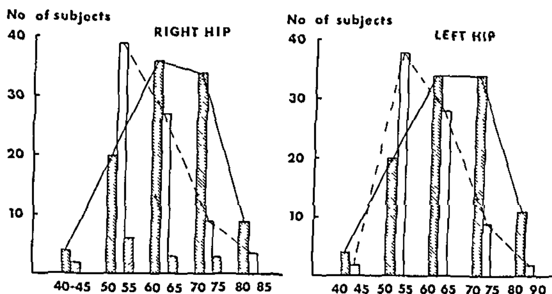
and a head circumference above the upper limit of normal.

Table 9 shows the range of passive flexion and Table 10 the range of passive extension. There was no statistically significant difference between groups A and B but the distribution curves of the values showed different patterns in groups A and B (Figure 3).

The range of passive abduction with hips extended is shown in Table 11. The difference between mean values for both

INTERNAL ROTATION OF THE HIP JOINT

GROUP	A	UNSTABLE HIPS, TREATED	129	SUBJ
"	B	CONTROLS	100	"
	C	UNSTABLE HIPS, UNTREATED	17	"
		TOTAL No	246	SUBJ



51 BOYS

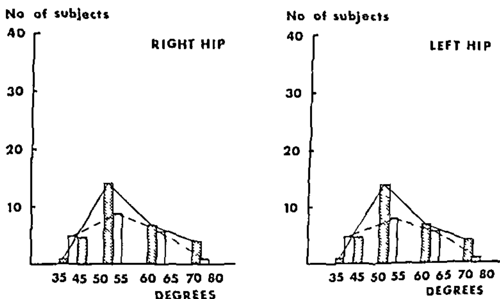


Figure 6 The range of passive internal rotation of the hip in 129 children with unstable hips at birth treated with Frejka's pillow, 100 healthy children and 17 children with unstable hips at birth untreated

Table 17 The passive external rotation of 4[illegible]0 hip joints in prone position at the age of four to six years in 1[illegible] children with unstable hips at birth treated with Frejkas pillow (Group A) 99 healthy children (Group B) and 1[illegible] children with unstable hips untreated (Group C)

Group	Boys			Girls				
					Right hip		Left hip	
	No	Degrees	S D	No	Degrees	S D	Degrees	S D
A	[illegible]6	35 96	7 35	103	35 72	11.51	35.39	11 41
B	20	41 00	6.81	9	39.37	5 85	39.37	5 85
C	5	34 00	8 94	1[illegible]	33 [illegible]	5 69	33 [illegible]5	5 69

Table 18 The acetabular angle (AC angle) at the age of four to six years in 1[illegible]9 children with unstable hips at birth treated with Frejkas pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys					Girls				
	No	Right hip		Left hip		No	Right hip		Left hip	
		Degrees	S D	Degrees	S D		Degrees	S D	Degrees	S D
A	6	15.81	3 49	15 46	3 63	103	15 43	4 55	15 20	3 94
B	20	13 [illegible]0	3 [illegible]0	13 80	3 37	80	13 86	3.53	13 86	3 36
C	5	13 40	3 21	13 40	3 21	12	13 83	4 26	13 33	4 52

of group A and boys of group B was statistically significant and the distribution curves of values showed slightly different patterns (Figure 4)

Table 12 shows the mean values of the range of passive adduction There was no statistically significant difference between the values of the three groups

Table 13 gives the mean value of passive abduction with the hips 90 flexed There is statistically no significant difference between the mean values of group A and group B but the groups have different patterns of the distribution curves (Figure 5)

Table 14 shows the mean values of the range of internal rotation with the hips 90 flexed The difference between values for girls from group A and girls from group B is statistically significant

Table 15 shows the mean values for external rotation in the supine position with the hips 90 flexed There is no statistically significant difference between groups A and B

Table 16 shows the range of internal rotation in the prone position The difference between mean values for girls of group A and girls of group B is statistically significant The distribution curves of the values for internal rotation show different patterns in group A and group B (Figure 6)

Table 17 shows the range of movements for passive external rotation in the prone position The difference between values of children from group A and B is statistically significant both for boys and girls The distribution curves of values for external rotation showed different patterns in group A and group B (Figure 7)

Evaluation of the muscular strength of the lower extremities revealed no gross abnormalities

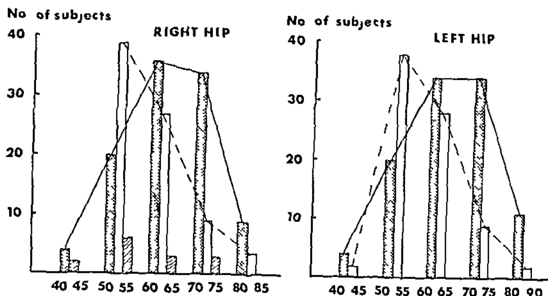
None of the subjects of the three groups A B and C had a positive Trendelenburg sign

In toeing when walking was observed in 22 children of group A representing 0 16 per cent of the total number In eight of the children the same observa

INTERNAL ROTATION OF THE HIP JOINT

GROUP A	UNSTABLE HIPS TREATED	129	SUBJ
" B	CONTROLS	100	"
C	UNSTABLE HIPS, UNTREATED	17	"
	TOTAL No	246	SUBJ

195 GIRLS



51 BOYS

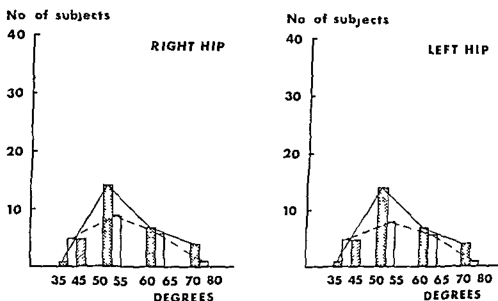


Figure 6 The range of passive internal rotation of the hip in 123 children with unstable hips at birth treated with Frejkas pillow 100 healthy children and 17 children with unstable hips at birth untreated

Table 19 Side difference of the angle of the acetabular roof (AC angle) at the age of four to six years in 1 9 children with unstable hips at birth treated with Frejkas pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Right side–left side in degrees	Groups A Boys No	%	Girls No	%	B Boys No	%	Girls No	%	C Boys No	%	Girls No	%
−4			1	1 0								
−3			4	3 9	1	5 0	3	3 7				
−2			9	8 7	3	15 0	6	7 5			1	8 3
−1 0 +1	22	84 6	74	69 9	13	65 0	63	78 7	5	100 0	8	66 7
+2	4	15 4	11	10 7	2	10 0	5	6 3			3	25 0
+3			3	2 9	1	5 0	3	3 7				
> +3			3	2 9								

Table 20 Wibergs CE angle at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips at birth untreated (Group C)

Group	No	B Right hip Degrees	S D	Left hip Degrees	S D	No	Girls Right hip Degrees	S D	Left hip Degrees	S D
A	26	28 92	4 72	30 04	4 83	103	29 51	5 19	30.82	5 21
B	20	31 30	4 50	32 00	4 86	80	31 26	5 15	32 46	5 03
C		32 80	2 86	33.80	5 02	12	32 67	4 31	34 00	4 69

Table 21 Side difference of Wibergs CE angle at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

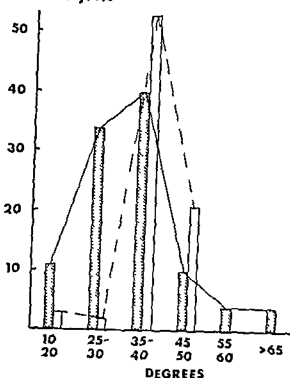
Right side–left side in degrees	Groups A Boys No	%	Girls No	%	B Boys No	%	Girls No	%	C Boys No	%	Girls No	%
6			3	2 9								
5			1	1 0			1	1 2				
4	1	3 8	4	3 9			3	3 7				
3	5	19 2	17	16 5	2	10 0	13	16 2	1	20 0		
2	2	7 7	14	13 6	6	30 0	22	27 5	1	20 0	1	8.3
1 0 +1	16	61 5	52	50 4	9	45 0	29	36 2	2	40 0	8	66 7
+2	2	7 7	8	7.8	2	10 0	8	10 0	1	20 0	3	25 0
+3			2	1 9	1	5 0	3	3 7				
4			2	1 9								
5							1	1 2				

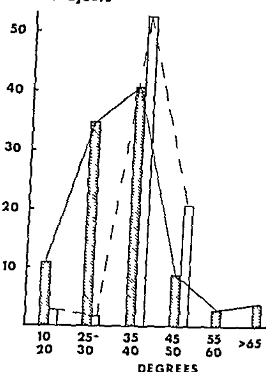
tion had been made by the parents Among the children of group B in toeing was observed in five representing 0 04 per cent of the total number In two of the subjects the same observation had been made by the parents Among the children of group C in toeing was recorded by the parents and on clinical

EXTERNAL ROTATION OF THE HIP JOINT

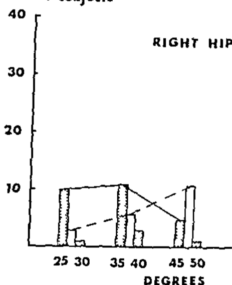
GROUP A	UNSTABLE HIPS TREATED		129 SUBJ
" B	CONTROLS		100 "
" C	UNSTABLE HIPS, UNTREATED		17 "
		TOTAL No	246 SUBJ

195 GIRLS





51 BOYS



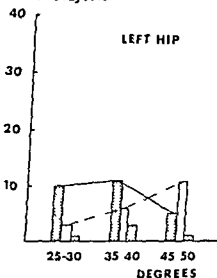
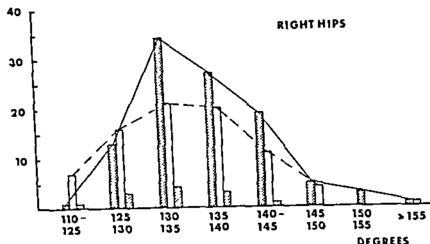


Figure 7 The range of passive external rotation movement of the hip in 129 children with unstable hips at birth treated with Frejkas pillow 100 healthy children and 17 children with unstable hips at birth untreated



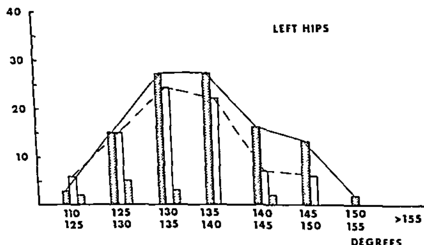
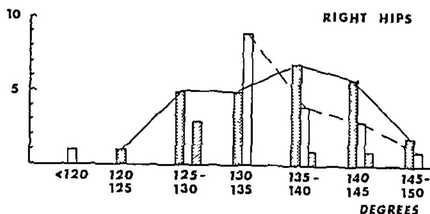


Figure 9 The f m ral ne k shaft angle (CCD-angle) in 103 girls with unstable hips at birth treated u th F r jkas p llow 80 h althy girls and 12 girls with unstable h ps at birth

statistically no significant difference for values of girls from group B and C

Table 21 compares the measurements of the CC angle of the right and left side 81 4 per cent of the children showed minimal differences between the two sides (0-2)

The mean values of the femoral neck shaft angle (CCD angle) are shown in Table 22 The difference between mean



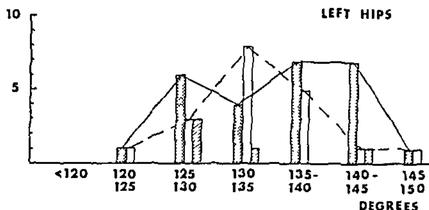


Figure 8 The femoral neck shaft angle (CCD angle) in 26 boys with unstable hips at birth treated with Frejlas pillow 20 healthy boys and 5 boys with unstable hips at birth untreated

examination in two cases and in addition in one child slight in toeing was recorded in the clinical observation only

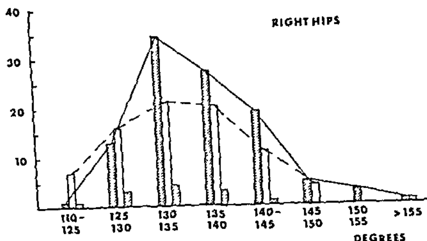
4 *Results of radiological examination at the age of 4 6 years*

Table 18 shows the mean values of the AC angle The difference between values of group A and group B is statistically significant for girls only

In Table 19 the values of the AC angle for the right and left side are compared 93 9 per cent of the children showed practically no difference between the two sides

Table 20 shows the mean values of the CE angle The mean value for girls of group A was statistically significantly lower than the mean value for girls of group B and girls of group C There was

	GROUP			
▭	GROUP A	UNSTABLE HIPS TREATED	103	SUBJ
▭	B	CONTROLS	80	
▭	C	UNSTABLE HIPS UNTREATED	12	
		TOTAL No	195	SUBJ



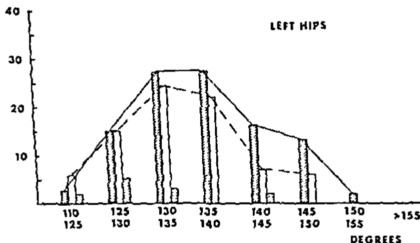


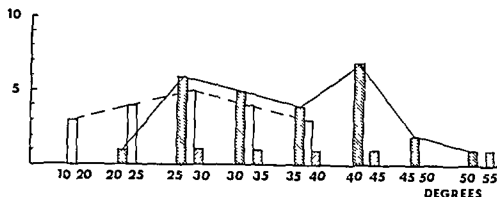
Figure 3 The femoral neck shaft angle (CCD angle) in 103 girls with unstable hips at birth treated with Frejka pillow, 80 healthy girls and 12 girls with unstable hips at birth.

statistically no significant difference for values of girls from group B and C

Table 21 compares the measurements of the CCD angle of the right and left side 81.4 per cent of the children showed minimal differences between the two sides (0-2°)

The mean values of the *femoral* neck shaft angle (CCD angle) are shown in Table 22 The difference between mean

GROUP A	UNSTABLE HIPS TREATED	26 SUBJ
» B	CONTROLS	20 »
» C	UNSTABLE HIPS, UNTREATED	5 »
	TOTAL No	51 SUBJ



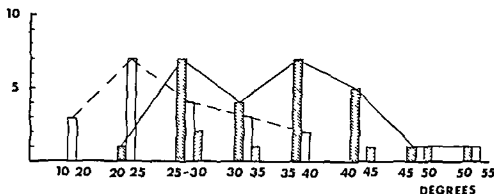
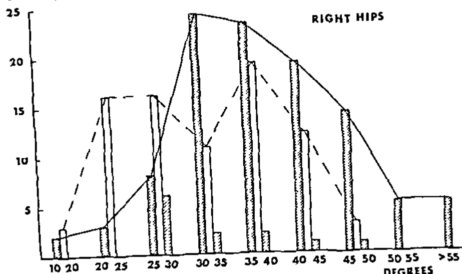


Figure 11 The anteversion angle of the femoral neck (AT angle) in 26 boys with unstable hips at birth 20 healthy boys and 5 boys with unstable hips at birth untreated

Table 26 The area of the epiphysis of the femoral head at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys No	Boys Right hip mm²	Boys Right hip SD	Boys Left hip mm²	Boys Left hip SD	Girls No	Girls Right hip mm²	Girls Right hip SD	Girls Left hip mm²	Girls Left hip SD
A	26	1135 44	238 79	1107 77	192 59	103	1124 81	250 84	1110 39	247 59
B	20	1181 71	227 04	1187 84	224 02	80	1[illegible]39 44	240 63	1[illegible]36 49	243 77
C	5	1308 16	240 33	1308 16	240 33	12	1526 81	488 27	1523 41	490 39

GROUP A	UNSTABLE HIPS	TREATED	103 SUBJ
B	CONTROLS		80
C	UNSTABLE HIPS	UNTREATED	12
		TOTAL No	195 SUBJ



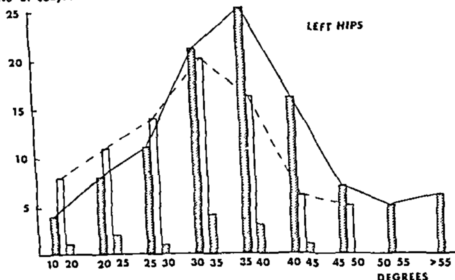


Figure 12 The anteversion angle of the femoral neck (AV angle) in 103 girls with unstable hips at birth treated with Frejka's pillow, 80 healthy girls and 12 girls with unstable hips at birth untreated

mean values of the groups A and B is not statistically significant

Table 26 shows the area of the epiphysis for the different groups The difference between values for groups A and B is not statistically significant

The form of the epiphysis expressed by the length/width ratio is shown in Table

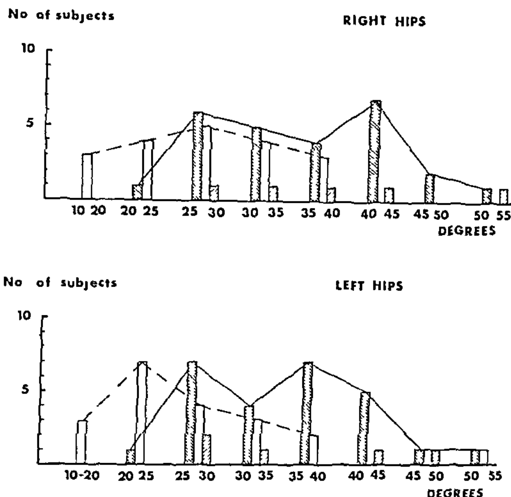
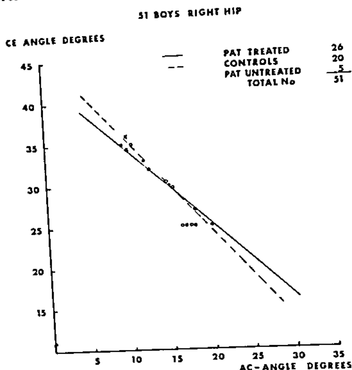


Figure 11 The anteversion angle of the femoral neck (AV angle) in 26 boys with unstable hips at birth 20 healthy boys and 5 boys with unstable hips at birth untreated

Table 26 The area of the epiphysis of the femoral head at the age of four to six years in 129 children with unstable hips at birth treated with Frejkas pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

Group	Boys No	Boys Right hip mm²	Boys Right hip S D	Boys Left hip mm²	Boys Left hip S D	Girls No	Girls Right hip mm²	Girls Right hip S D	Girls Left hip mm²	Girls Left hip S D
A	26	1135 44	238 79	1107 77	19? 59	103	1124 81	256 84	1116 39	247 59
B	20	1181 71	227 04	1187 84	224 02	80	1239 44	240 63	1?36 49	243 77
C	5	1308 16	240 33	1308 16	240 33	12	15?6 81	488 27	1523 41	430 39

Figure 14 The correlation of the CE angle and AC angle of the right hip in 26 boys with unstable hips at birth treated with Frejkas pillow 20 healthy boys and 5 boys with unstable hips at birth untreated



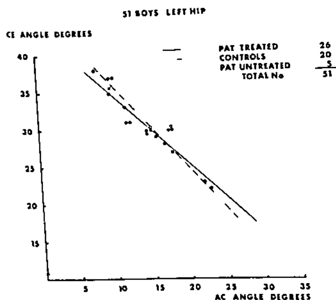


Figure 15 The correlation of the CE angle and AC angle of the left hip in 26 boys with unstable hips at birth treated with Frejkas pillow 20 healthy boys and 5 boys with unstable hips untreated

AC angle of boys in the right and left hip respectively The correlation coefficient (cor coef) of group A was −0 66 and that of group B —0 85 The slight difference between group A and group B is without practical importance

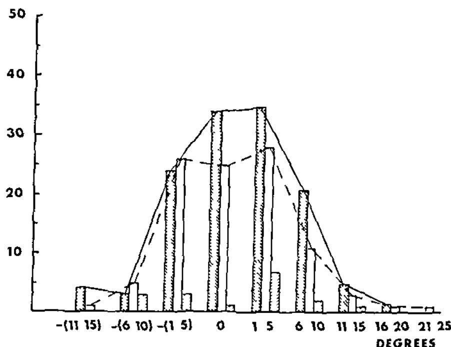


Figure 13 Values of the CE angle of the right hip and the left hip in 129 children with unstable hips at birth treated with Frejka pillow 100 healthy children and 17 children with unstable hips at birth untreated

Table 27 The length/width ratio of the epiphysis of the femoral head at the age of four to six years in 129 children with unstable hips at birth treated with Frejka pillow (Group A) 100 healthy children (Group B) and 17 children with unstable hips untreated (Group C)

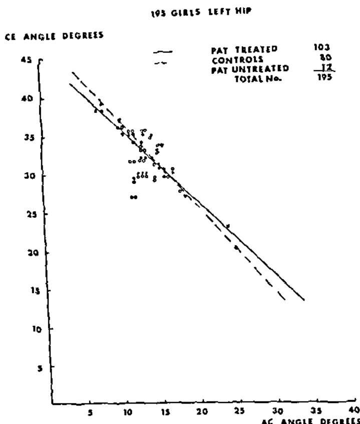
Group	No	Boys				No	Girls			
		Right hip		Left hip			Right hip		Left hip	
		L/W	S D	L/W	S D		L/W	S D	L/W	S D
A	26	2 04	0 16	2 05	0 17	103	2 08	0 31	2 05	0 20
B	20	1 93	0 19	1 93	0 19	80	1 99	0 19	2 00	0 19
C	5	2 12	0 20	2 12	0 20	12	2 22	0 15	2 21	0 15

27 There is no difference between the groups The values for children of group C were not computed as they included some relatively older children

5 *Correlation of the radiological results*

Figure 14 and Figure 15 illustrate the correlation of values of the CE angle and

Figure 17 The correlation of the CE angle and AC angle of the left hip in 103 girls with unstable hips at birth 80 healthy girls and 12 girls with unstable hips at birth untreated



correlation between values of the AV angle of girls and the age of the subjects In group A the cor coef was 0 07 for the right hip and 0 08 for the left In group B the corresponding values were −0 41 and 0 20 The small number of values for group C yielded cor coef of −0 14 and 0 35 for the right and left side respectively

Table 28 shows the correlation between the length and width of the epiphysis and the age of the subjects The girls of both group A and group B showed a definite correlation whereas no correlation was found in boys In group C there was a positive correlation for all groups of values except for the width of the epiphysis of boys

No correlation was found between the values of the CE angle and CCD angle and the age of the subjects

As can be seen from the Table 29 there is no relation between the age when the children started to walk without support and the values of the AV angle Those results are based upon informations from the parents of 72 children of group A

Table 30 shows the average values of the AV angle of 11 children of group A who showed a gradual increase of passive internal rotation during the first year of life The average value for boys was 37 8 for the right hip and 34 6 for the left hip The corresponding values for girls were 45 8 and 39 5 The latter values are near the upper normal level

In Table 31 is shown the correlation between the height/weight ratio of the children and the values of the AV CCD and CE-angles Individuals with height/weight ratio below the 50th percentile have statistically significantly higher

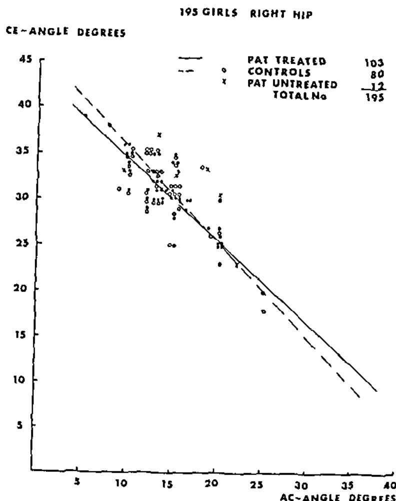


Figure 16 The correlation of the CE angle and AC angle of the right hip in 103 girls with unstable hips at birth treated with Frejkas pillow 80 healthy girls and 12 girls with unstable hips at birth untreated

Figure 16 and Figure 17 show the correlation between values of the CE angle and the AC angle of girls in the right hip and the left hip respectively The cor coef of group A was — 0 72 and that of group B — 0 75 The difference between the two groups is without practical importance

Figure 18 shows an attempt to find a possible correlation between values of the CE angle and AV angle No correlation could be proved but the regression lines of values of group A and values of group B were different

No correlation could be found between the retarded ossification of the femoral head and increased anteversion of the femoral neck

No correlation could be found between values of the AV angle and the CCD angle (cor coef 0 27)

6 *Correlation of some clinical and radiological findings*

Figure 19 illustrates the correlation between the passive internal rotation movement and the values of the AV angle The correlation was very poor (cor coef 0 52) For the sake of simplicity only the figures for the left hip of the girls in the prone position are shown but the same results were obtained for the rest of the material

Figure 20 shows the values of the AV angle of boys related to the age of the subjects There is no correlation for values in group A (cor coef of the right hip 0 027 and the left hip 0 035) In group B the corresponding figures for the cor coef are — 0 41 and — 0 397 and in group C — 0 61 and — 0 397

Figure 21 and Figure 22 illustrate the

Figure 18 The correlation of the CE angle and AV angle of the right hip in 103 girls with unstable hips at birth treated with Frejkas pillow 80 healthy girls and 12 girls with unstable hips at birth untreated

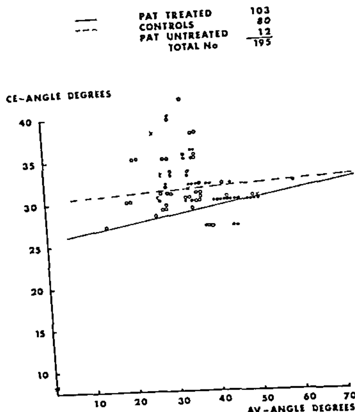


Table 29 The AV angle in relation to the development of walking in children with unstable hips at birth

Age of walking without support in months	AV angle in degrees (left hip)				
	20–29	30–39	40–49	50–59	59
9 12	6	9	9	3	0
13 15	8	18	4	3	1
16–19	4	9	4	1	0

Conclusion normal clinical and radiological findings

2 *Patient no 1 An 040569 Female*

No cases of CDH in the family Breech presentation The birth induced by oxytocin Positive dislocation test in the left hip on the second day of life Treated with Frejkas cushion splint for three months At that age normal clinical findings

Walked without support 14 months old

Sixteen months of age internal rotation 90 external rotation 90 abduction 80 X ray picture normal

Six years old flexion 135 extension 20 abduction 40 internal rotation 75 external rotation 10 Hips 90 flexed

Table 28. Length and width of the epiphysis of the femoral head correlated with age in 129 children with unstable hips at birth treated with Frejka's pillow (Group A), 100 healthy children (Group B) and 17 children with unstable hips at birth untreated (Group C)

Group	No	Sex	Length (L) Width (W)	Right (R) Left (L)	Slope of regression line	Correlation	Significance
A	26	M	L	R	0.12150	0.24522	0.11364
			L	L	0.10016	0.22871	0.13055
			W	R	0.05140	0.18891	0.17719
			W	L	0.00217	0.00917	0.48228
A	103	F	L	R	0.22102	0.47952	0.00001
			L	L	0.22109	0.49599	0.00001
			W	R	0.08108	0.30541	0.00085
			W	L	0.08110	0.39537	0.00040
B	20	M	L	R	0.21934	0.47791	0.03160
			L	L	0.21360	0.40717	0.21360
			W	R	0.08911	0.30214	0.09771
			W	L	0.08151	0.38550	0.11120
B	80	F	L	R	0.23455	0.56400	0.00001
			L	L	0.23631	0.56493	0.00001
			W	R	0.07292	0.33318	0.00173
			W	L	0.07414	0.32168	0.00181
C	5	M	L	R	0.25399	0.96993	0.00312
			L	L	0.25399	0.96993	0.00312
			W	R	0.04494	0.38945	0.25849
			W	L	0.04494	0.38945	0.25849
C	12	F	L	R	0.28836	0.93030	0.00001
			L	L	0.29043	0.92973	0.00001
			W	R	0.12110	0.91738	0.00001
			W	L	0.12110	0.91738	0.00001

values of the AV angle than those with a ratio above the 50th percentile. The values for the CCD and CE angles showed no significant difference between the two groups.

CASE HISTORIES

The following case histories illustrate some of the characteristic findings for the different categories of patients.

1. *Patient no. 39 Da. 101269. Male.*

No known cases of CDH in the family. Vertex presentation. Positive dislocation test in the left hip on the first day of life, negative on the fourth day. Frejka's pillow used for three months. At that age normal clinical findings.

Six months old: internal rotation 70°, external rotation 90°, abduction 90°. X-ray: possibly indistinctly marked lateral margin of the left acetabulum.

Eighteen months: internal rotation 50°, external rotation 80°, abduction 80°. X-ray: normal findings.

Six years of age: flexion 135°, extension 20°, abduction 50°, internal rotation 50°, external rotation 45°. Hips 90° flexed: abduction 55°, internal rotation 50°, external rotation 45°. X-ray: femoral epiphysis 29 × 14 mm. AC angle 12°, CE angle 28°, CCD angle 140°, AV angle 26° (Figure 23).

Figure 18 The correlation of the CE-angle and AV angle of the right hip in 103 girls with unstable hips at birth treated with Frejkas pillow 80 healthy girls and 12 girls with unstable hips at birth untreated

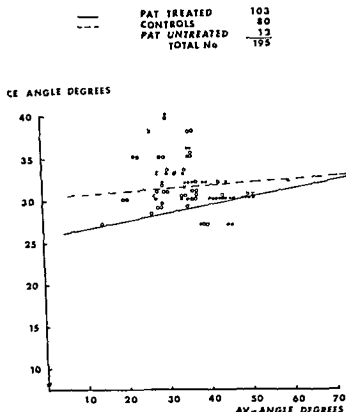


Table 29 The AV angle in relation to the development of walking in children with unstable hips at birth

Age of walking without support in months	AV angle in degrees (left hip)				
	0–29	30–39	40–49	50–59	59
9 12	6	9	9	3	0
13 15	8	18	4	3	1
16–19	4	2	4	1	0

Conclusion normal clinical and radiological findings

2 Patient no 1 Au 010563 Female

No cases of CDH in the family Breech presentation The birth induced by oxytocin Positive dislocation test in the left hip on the second day of life Treated with Frejkas cushion splint for three months At that age normal clinical findings

Walked without support 14 months old

Sixteen months of age internal rotation 90 external rotation 90 abduction 80 X ray picture normal

Six years old flexion 135 extension 20 abduction 40 internal rotation 75 external rotation 10 Hips 90 flexed

Table 28. Length and width of the epiphysis of the femoral head correlated with age in 129 children with unstable hips at birth treated with Frejka's pillow (Group A), 100 healthy children (Group B) and 17 children with unstable hips at birth untreated (Group C)

Group	No	Sex	Length (L) Width (W)	Right (R) Left (L)	Slope of regression line	Correlation	Significance
A	26	M	L	R	0.12150	0.24[illegible]2[illegible]	0.11364
			L	L	0.10016	0.22871	0.13055
			W	R	0.05140	0.18891	0.1[illegible]
			W	L	0.00217	0.00917	0.48[illegible]8
A	103	F	L	R	0.22102	0.4725[illegible]	0.00001
			L	L	0.22109	0.49[illegible]99	0.00001
			W	R	0.08108	0.30541	0.00085
			W	L	0.08110	0.32[illegible]37	0.00040
B	20	M	L	R	0.21934	0.42[illegible]91	0.03160
			L	L	0.21360	0.40717	0.[illegible]13[illegible]0
			W	R	0.08911	0.30914	0.09771
			W	L	0.091[illegible]1	0.[illegible]8550	0.11120
B	80	F	L	R	0.234[illegible]	0.56400	0.00001
			L	L	0.23631	0.56493	0.00001
			W	R	0.07292	0.32318	0.00173
			W	L	0.07414	0.32168	0.00181
C	5	M	L	R	0.25399	0.96993	0.00312
			L	L	0.25399	0.96993	0.00312
			W	R	0.04494	0.38945	0.[illegible]849
			W	L	0.04494	0.38945	0.25849
C	12	F	L	R	0.28836	0.9[illegible]930	0.00001
			L	L	0.29043	0.92973	0.00001
			W	R	0.12110	0.01738	0.00001
			W	L	0.12110	0.91738	0.00001

values of the AV angle than those with a ratio above the 50th percentile. The values for the CCD and CE angles showed no significant difference between the two groups.

CASE HISTORIES

The following case histories illustrate some of the characteristic findings for the different categories of patients.

1. *Patient no. 39 Da 101269. Male.*

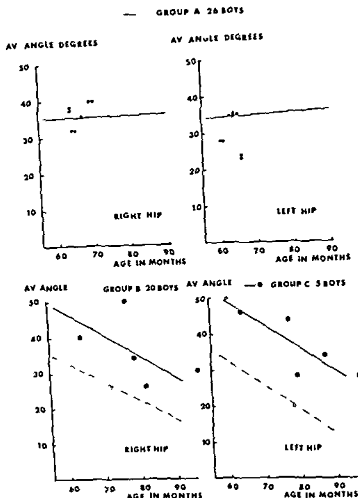
No known cases of CDH in the family. Vertex presentation. Positive dislocation test in the left hip on the first day of life, negative on the fourth day. Frejka's pillow used for three months. At that age normal clinical findings.

Six months old: internal rotation 70, external rotation 90, abduction 90. X-ray: possibly indistinctly marked lateral margin of the left acetabulum.

Eighteen months: internal rotation 50, external rotation 80, abduction 80. X-ray: normal findings.

Six years of age: flexion 13[illegible], extension 20, abduction 50, internal rotation 50, external rotation 15. Hips 90 flexed: abduction 55, internal rotation 50, external rotation 1[illegible]. X-ray: femoral epiphysis 29 × 14 mm, AC angle 12, CE angle 28, CCD angle 140, AV angle 26 (Figure 23).

Figure 0 The values of the AV angle related to the age of 26 boys with unstable hips at birth treated with Frejkas pill w 20 healthy boys and 5 boys with unstable hips at birth untr ated



Tabl 31 The r lation betwe n the he ght/we ght ratio of 123 childr n and the AV CCD- and CE angle

Height Weight ratio	AV angle		CCD angle		CE angle	
	Mean	S D	Mean	S D	Mean	S D
‹ 0 p rcentiles	37 20	9 74	13 ; 47	6 43	30.32	4.82
› 0 percentiles	32 68	8 56	135 97	5 80	30 44	5 43

Conclusion increased range of passive internal rotation Increased anteversion of the femoral neck

3 *Patient no 133 Hu 0;0170 Male*

No cases of CDH in the family Vertex presentation Birth weight 2830 g Dys mature appearance Positive dislocation test in both hips on the second day nega tive on the eight day Treated with Frej kas pillow

Three months old internal rotation *60* external rotation 80 abduction *right side 80* left side *60* Treatment with Frejkas pillow continued to five months

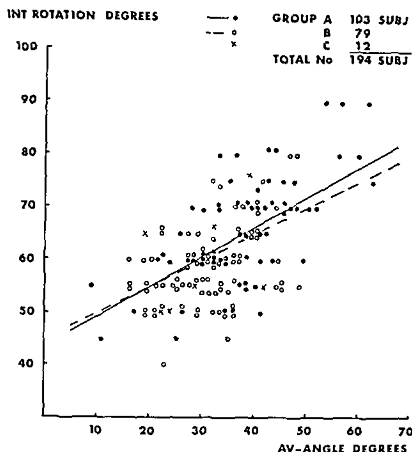


Figure 19 The correlation between the passive internal rotation and the AV angle of the left hip in 103 girls with unstable hips at birth treated with Frejkas pillow 79 healthy girls and 12 girls with unstable hips at birth untreated

Table 30 The AV angle at four to six years in relation to the increasing passive internal rotation during infancy Observations in 11 children with unstable hips at birth

No	Sex	AV angle in degrees Right hip	Mean	Left hip	Mean
1	M	40		40	
2	M	43		35	
3	M	41	37 8	39	34 6
4	M	39	(boys)	33	(boys)
5	M	26		26	
6	F	44		37	
7	F	36		36	
8	F	50	43 8	50	39 5
9	F	45	(girls)	40	(girls)
10	F	39		32	
11	F	43		42	

internal rotation 75 external rotation 34 CCD angle right side 138 left side 140 abduction 50 X ray femoral epiphysis 32 × 12 mm AC angle 10 CE angle 10 AV angle right side 63 left side 62 (Figure 24)

Conclusion asymmetrical development of the hip joint both on clinical and radiological examination

5 *Patient no 119 Mau 140970 Female*

No cases of CDH in the family Breech presentation forceps delivery Birth weight 2620 g Dysmature appearance Positive dislocation test in the right hip on the first day of life negative on the third day Treated with *Frejkas pillow* for three months Did not come to follow up afterwards

Five years old

Position		Movement	*right hip*	*left hip*
supine	hips 0	flexion	120	120
		abduction	25	35
		adduction	20	20
	hip 90 *flexed*	abduction	15	30
		internal rotation	65	50
		external rotation	45	45
prone		extension	25	25
		internal rotation	40	40
		external rotation	20	30
X ray findings (Figure 27)		femoral epiphysis	24 × 11 mm	24 × 11 mm
		AC angle	15	10
		CE-angle	30	35
		CCD angle	143	141
		AV angle	53	44

Conclusion restricted movements and increased internal rotation of the right hip Increased anteversion of the right femoral neck

6 *Patient no 31 So 281069 Female*

No hip anomalies in the family Vertex presentation birth induced by oxytocin A positive dislocation test on the second day of life negative on the fourth day Treated with Frejkas pillow for three months at that stage normal clinical finding

Eight months internal rotation 80 external rotation 90 abduction 90 Walked without support 15 months old

Seventeen months internal rotation [illegible] external rotation 90 abduction 80° Shortly afterwards the mother observed that the child did not move her left arm normally and slight spasticity of the left leg was noticed Treated with *physiotherapy*

Five and a half years old flexion 115 extension 20 abduction 50 adduction 15 internal rotation 60 external rotation 50 Hips 90 flexed abduction 50 internal rotation 35 external rotation 70

X ray findings (*Figure 28*)

	right hip	left hip
Femoral epiphysis	32 × 16 mm	3[illegible] × 14 mm
AC-angle	15	21
CE angle	20	[illegible]0
CCD angle	140	147
AV angle	17	23

Conclusion cerebral palsy Left sided hemiparesis Relatively increased anteversion of the left femoral neck

7 *Patient no 71 Ve 251270 Female*

No hip abnormalities in the family Breech presentation forceps delivery Erythroblastosis foetalis Fourteen hours

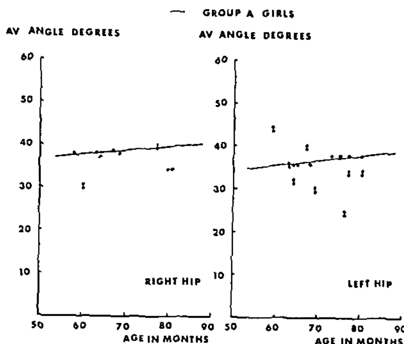


Figure 24 The values of the AV angle related to the age of 103 girls with unstable hips at birth treated with Frejkas pillow

Nine months internal rotation 40 external rotation 80° abduction 60° X-ray negative

Five years old flexion 135 extension 20 abduction 40° *internal rotation* 60 external rotation 45 Hips 90 flexed internal and external rotation 60° abduction 45° X ray femoral epiphysis right side 26 × 11 mm left side 24 × 12 mm AC angle 17 CE angle right side 24 left side 28 CCD angle right side 134° left side 138 AV angle right side 25 left side 38 (Figure 25)

Conclusion asymmetrical development of the hip joint Relative increase of the anteversion of the femoral neck of the left side Normal clinical findings

4 *Patient no 77 Ne 230271 Female*

No known hip anomalies in the family Vertex presentation Positive dislocation test in the left hip on the first day of life negative on the fourth day Treated with Frejkas pillow for three months did not come to follow up afterwards

Five years old

Position		Movement	right hip	left hip
supine	hips 0	flexion	135	135
		abduction	45	45
		adduction	20	20
	hips 90 flexed	abduction	55	55
		internal rotation	55	65
		external rotation	60	60
prone		extension	25	2
		internal rotation	60	0
		external rotation	[illegible]	40
X ray findings (Figure 26)		femoral epiphysis	29 × 14 mm	29 × 14 mm
		AC angle	12	12
		CE angle	29	29
		CCD angle	144	141
		AV angle	31	38

Conclusion asymmetrical development of the hip joint both on clinical and radiological examination

5 *Patient no 119 Mau 140970 Female*

No cases of CDH in the family Breech presentation forceps delivery Birth weight 2620 g Dysmature appearance Positive dislocation test in the right hip on the first day of life negative on the third day Treated with Frejkas pillow for three months Did not come to follow-up afterwards

Five years old

Position		Movement	right hip	left hip
supine	hip 0	flexion	120	1 0
		abduction	25	35
		adduction	20	20
	hips 90 flexed	abduction	15	30
		internal rotation	65	50
		external rotation	45	45
prone		extension	25	25
		internal rotation	40	70
		external rotation	90	30
X ray findings (Figure 27)		femoral epiphysis	24 × 11 mm	24 × 11 mm
		AC angle	15	10
		CE angle	30	35
		CCD angle	143	141
		AV angle	53	44

Conclusion restricted movements and increased internal rotation of the right hip Increased anteversion of the right femoral neck

6 *Patient no 31 So 281069 Female*

No hip anomalies in the family Vertex presentation birth induced by oxytocin A positive dislocation test on the second day of life negative on the fourth day Treated with Frejkas pillow for three months at that stage normal clinical findings

Eight months internal rotation 80 external rotation 90 abduction 90 Walked without support 15 months old

Seventeen months internal rotation 4 external rotation 90 abduction 80 Shortly afterwards the mother observed that the child did not move her left arm normally and slight spasticity of the left leg was noticed Treated with physiotherapy

Five and a half years old flexion 115 extension 20 abduction 50 adduction 15 internal rotation 60 external rotation 50 Hips 90 flexed abduction 50 internal rotation 35 external rotation 70

X ray findings (Figure 28)

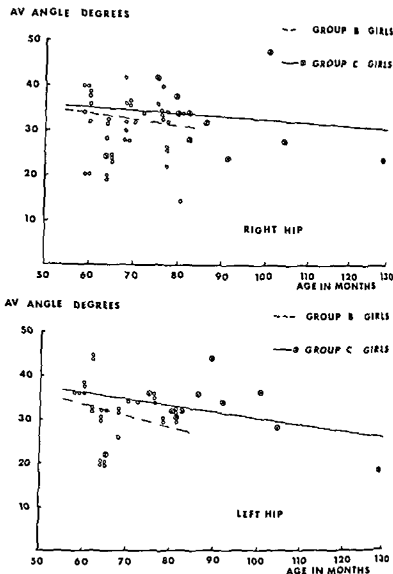
	right hip	left hip
Femoral epiphysis	32 × 16 mm	32 × 14 mm
AC angle	15	21
CE angle	20	20
CCD angle	140	143
AV angle	17	23

Conclusion cerebral palsy Left sided hemiparesis Relatively increased anteversion of the left femoral neck

7 *Patient no 41 Ne 241270 Female*

No hip abnormalities in the family Breech presentation forceps delivery Erythroblastosis foetalis Fourteen hours

Figure 22 The values of the AV angle related to the age of 80 healthy girls and 12 girls with unstable hips at birth untreated



after birth an exchange transfusion was performed because of hyperbilirubinaemia Positive dislocation test in the *right hip on the first day of life negative* on the fourth day Treated with Frejkas cushion splint for three months

Three months old internal and external rotation 45 abduction 90° The child showed a marked retardation of neuromuscular development and was hypotonic

Eight months *internal rotation 10* external rotation 80 abduction 70 X-ray picture was normal

Five years length 105 cm (10 perc) Weight 13 1 g (below 2 5 perc) General spasticity Flexion of the hips 115 extension 15°, abduction 40 adduction 30 internal rotation 90 external rotation 60 Hips 90 flexed abduction 45° *internal rotation 80* external rotation 70 X ray femoral epiphysis 17 × 10 mm AC angle 25 CE angle right side 16 left side 24 CCD angle right side 151° left side 154 AV angle right side 67 left side 61° (Figure 29)

Conclusion cerebral palsy Bilateral increase of the anteversion of the femoral neck

8 *Patient no 777 Gu 210970 Female*

Positive dislocation in the right hip on the second day of life negative on the *fifth day No treatment instituted*

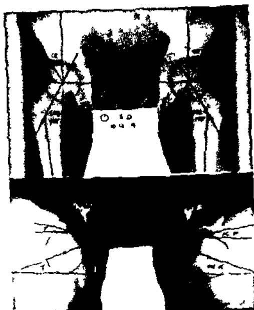


Figure 23 Radiological examination of a six years old boy with a positive dislocation test in the left hip at birth R Normal findings



Figure 2? Radiological examinati n of a five years ld boy with a positive dislocation test in both hips at birth R Asymmetrical development f the hip joint AV angle on the right s de 25 on the left s de 38



F gu 24 Radi l g al x m nation of a six y a ll girl (th a po it e li locat n test in th l ft h p at b th R In r as d ant v rsi n of th f o f n k AV angl n th right side 63 the l ft l 62



Figur C Radiological examinati n of a five y ars ol l girl with a p sitive dislo at on test in the l ft h p at birth R Asymmetric al development f the hip AV angl n the r ght side 31 n th l ft side 8

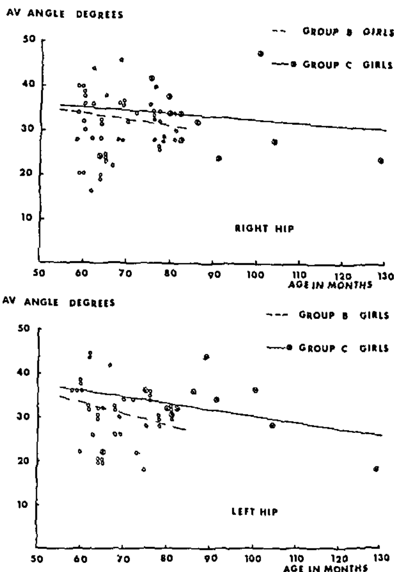


Figure 22 The values of the AV angle related to the age of 80 healthy girls and 12 girls with unstable hips at birth untreated

after birth an exchange transfusion was performed because of hyperbilirubinaemia Positive dislocation test in the right hip on the first day of life negative on the fourth day Treated with Frejka's cushion splint for three months

Three months old internal and external rotation 45 abduction 90 The child showed a marked retardation of neuromuscular development and was hypotonic

Eight months internal rotation 40 external rotation 80 abduction 70 X ray picture was normal

Five years length 105 cm (10 perc) Weight 13 kg (below 2 5 perc) General spasticity Flexion of the hips 115 extension 15 abduction 40 adduction 30 internal rotation 90° external rotation 60° Hips 90° flexed abduction 45 internal rotation 80 external rotation 70 X ray femoral epiphysis 17 × 10 mm AC angle 25 , CE angle right side 16° left side 24 CCD angle right side 151 left side 151 AV angle right side 67° left side 61 (Figure 29)

Conclusion cerebral palsy Bilateral increase of the anteversion of the femoral neck

8 *Patient no 777 Gn 240970 Female*

Positive dislocation in the right hip on the second day of life negative on the fifth day No treatment instituted

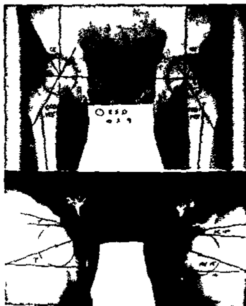


Figure 23 Radiological examination of a six years old boy with a positive dislocation test in the left hip at birth R Normal findings



Figure 25 Radiological examination of a five years old boy with a positive dislocation test in both hips at birth R Asymmetrical development of the hip joint AV angle on the right side 25 on the left side 8

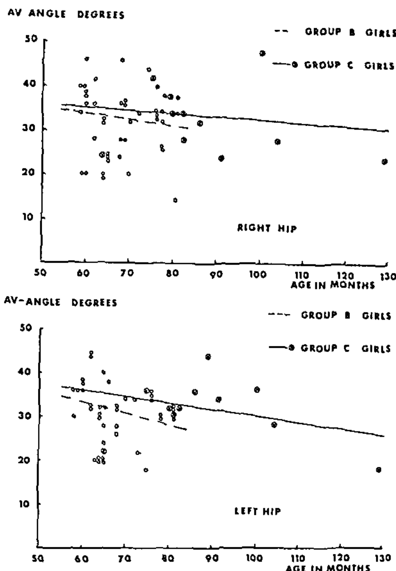


Figure 24 Radiological examination of a six years old girl with a positive dislocation test in the left hip at birth R Increased anteversion of the femoral neck AV angle on the right side 63 on the left side 6



Figure 26 Radiological examination of a five years old girl with a positive dislocation test in the left hip at birth R Asymmetrical development of the hip AV-angle on the right side 1 on the left side 38

Figure 22 The values of the AV angle related to the age of 80 healthy girls and 12 girls with unstable hips at birth untreated



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Eight months internal rotation 40 external rotation 80 abduction 70 X ray picture was normal

Five years length 105 cm (10 perc) Weight 13 1 g (below 2 5 perc) General spasticity Flexion of the hips 115° extension 15 abduction 40 adduction 30 internal rotation 90 external rotation 60 Hips 90 flexed abduction 45 internal rotation 80 , external rotation 70 X ray femoral epiphysis 17 × 10 mm AC angle 25 CE angle right side 16 left side 24 CCD angle right side 151° left side 154 AV angle right side 67 left side 61 (Figure 29)

Conclusion cerebral palsy Bilateral increase of the anteversion of the femoral neck

8 *Patient no 777 Gn 210970 Female*

Positive dislocation in the right hip on the second day of life negative on the fifth day No treatment instituted

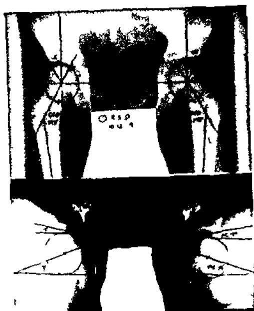


Figure 23 Radiological examination of a six years old boy with a positive dislocation test in the left hip at birth R Normal findings



Figure 25 Radiological examination of a five years old boy with a positive dislocation test in both hips at birth. R Asymmetrical development of the hip joint AV angle on the right side 25 on the left side 38



Figure 25 Radiological examination of a [illegible] years old girl with a positive dislocation test in the left hip at birth R [illegible] on [illegible] AV angle on the right side [illegible] on the left side [illegible]

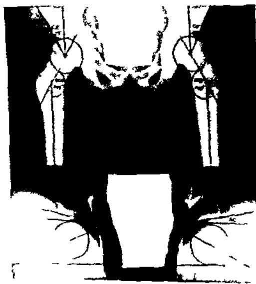


Figure 26 Radiological examination of a five years old girl with a positive dislocation test in the left hip at birth R Asymmetrical development of the hip AV angle on the right side 31 on the left side 38

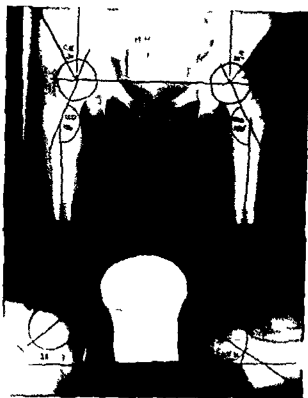


Figure 27 Radiological examination of a five years old girl with a positive dislocation test in the right hip at birth R Increased anteversion of the femoral neck of the right hip (AV angle 53) AV angle on the left side 44



Figure 29 Radiological examination of a five years old girl with a positive dislocation test in the right hip at birth R Cerebral palsy Cerebral spasticity Bilateral increase of the anteversion of the femoral neck AV angle right 67 left 61

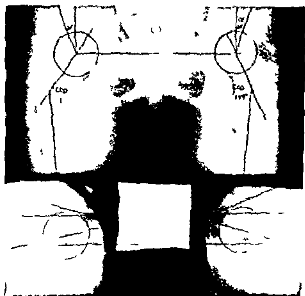


Figure 28 Radiological examination of a five years old girl with a positive dislocation test in both hips at birth R Cerebral palsy Hemiparesis sin Asymmetrical development of the hips AV angle on the right side 17 on the left side 23



Figure 30 Radiological examination of a six years old girl with a positive dislocation test in the right hip at birth left untreated R Normal findings

Clinical and radiological controls at two six and eighteen months of age revealed nothing pathological. Walked without support 11 months old.

Six years old flexion 125 extension 20 abduction 50 adduction 20 internal rotation 50 external rotation 55. Hips 90 flexed abduction 60 internal rotation 55 external rotation 60. X-ray femoral epiphysis 25 × 12 mm. AC-angle 20. CE-angle right side 30 left side 34. CCD angle right side 135 left side 130. AV angle right side 26 left side 22 (Figure 30).

Conclusion clinically and radiologically normal findings.

DISCUSSION

1 *Patients and methods*

*The Trondheim area offers good con*ditions for the investigation of the problems of congenital dislocation of the hip. All children are delivered in two maternity clinics and examination of the newborn are performed by few experienced pediatricians. All cases of the late diagnosis dislocation of the hip are referred to the orthopaedic department of the Regional Hospital.

The frequency of unstable hips in the present material was *22.4 ‰*. Apart from data reported by Harlem (1961) and Ramstad (1964) the incidence in Trondheim is the highest reported in Norway (Kvass 1961 Medbo 1961 Torp 1961 Nja 1962 Bjerkreim 1974 Hoyer 1975). Among the widely differing results published *from different countries it is not difficult to find incidence of unstable hips similar to ours (James & Sevastieoglou 1970 Fredensborg 1976)*. Apart from the fact that incidence of unstable hips of the newborn in Trondheim has shown a tendency to decrease during recent years (from 20 to 15 ‰) the findings have been remarkably stable and there is reason to believe that the figure of 22 ‰ represents the true incidence of unstable hips of newborn in the region.

In the examination of the newborn I used both the abduction test and the subluxation provocation test (Palmen 1957 Barlow 1962). I did not try to classify unstable hips into dislocated and dislocatable (Finlay et al 1967 Barlow 1962 Rosenblum et al 1972 *Siffert et al* 1972 Komprda 1974) as I had a strong impression that it depended largely on the position of the legs whether I found the hips in or out of joint at the time of examination. Atypical clicks of the hip joint were not recorded as they seem to be without *clinical significance (Sommer* 1971).

The sex distribution side affected and the incidence of breech presentation are in accordance with the results of other neonatal series (Palmen 1961 Hirsch & Scheller 1970 Lauritzen 1971 Huttova et al 1972 Ritter 1973 Bjerkreim 1974 Ackermann et al 1974 Artz et al 1975).

One of the main problems of the present investigation was to find a suitable group of control children. Being aware of the sex and racial variations of the incidence of CDH (Getz 1955) geographical distribution (Bjerkreim 1974) seasonal fluctuations (Record & Edwards 1958 Nagura 1955 Pap 1956 Uibe 1959 Chen et al 1970 Andren & Palmen 1963) and possible other factors in the pathogenesis of neonatal CDH I tried to find a control group within the population of Trondheim.

I sent an inquiry to all the parents of the children of the same sex born chronologically next to the children with unstable hips. All those children had been examined by me at birth. They had stable hips and received no treatment. One can *not be sure that the group represents com*pletely "normal" material. In a few cases the parents reported of hip abnormalities in the family. The control group differed *from the* patient group with respect to *birth order* of the child in the family. In

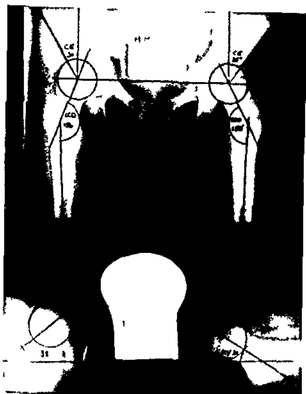


Figure 27 Radiological examination of a five years old girl with a positive dislocation test in the right hip at birth R Increased anteversion of the femoral neck of the right hip (AV angle 53) AV angle on the left side 44

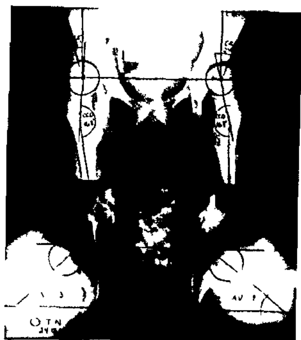


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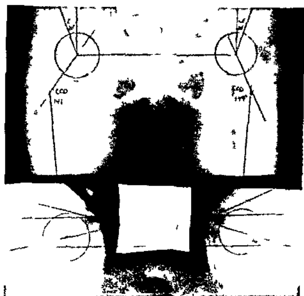


Figure 28 Radiological examination of a five years old girl with a positive dislocation test in both hips at birth R Cerebral palsy Hemiparesis sin Asymmetrical development of the hips AV angle on the right side 17 on the left side 25

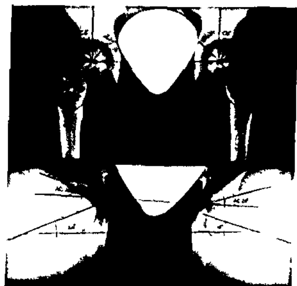


Figure 30 Radiological examination of a six years old girl with a positive dislocation test in the right hip at birth left untreated R Normal findings

Clinical and radiological controls at two six and eighteen months of age revealed nothing pathological Walked without support 11 months old

Six years old flexion 125 extension 90 abduction 50 adduction 20 internal rotation 50 external rotation 35 Hips 90 flexed abduction 60 internal rotation 55 external rotation 60 X ray femoral epiphysis 25 × 12 mm AC-angle 20 CE-angle right side 30 left side 31 CCD angle right side 135 left side 130 AV angle right side 26 left side 22 (Figure 30)

Conclusion clinically and radiologically normal findings

DISCUSSION

1 *Patients and methods*

The Trondheim area offers good conditions for the investigation of the problems of congenital dislocation of the hip All children are delivered in two maternity clinics and examination of the newborn are performed by few experienced pediatricians All cases of the "late diagnosis dislocation of the hip are referred to the orthopaedic department of the Regional Hospital

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I sent an inquiry to all the parents of the children of the same sex born chronologically next to the children with unstable hips All those children had been examined by me at birth They had stable hips and received no treatment One can not be sure that the group represents completely normal material In a few cases the parents reported of hip abnormalities in the family The control group differed from the patient group with respect to birth order of the child in the family In

the patient group (A) 75 children (58 per cent) were first born whereas in the control group (B) 39 children (39 per cent) wer first born The control group and the patient group were not matched for possible differences in social class distribution One boy originally in the control group revealed serious abnormalities of the hip joint probably due to Calve Legg Perthes disease This child was excluded from the series Another girl with a probable developmental anomaly of the lower extremities was also excluded

Nearly 70 per cent of the parents of the control children responded to the inquiry Among the remainder the majority had moved from the town and some refused the examination One cannot exclude the possibility that among the 30 per cent children not examined there might be so many pathological findings that the differences between groups A and B might be minimized It is not very likely however as parents generally are aware of even small abnormalities of their childrens development In addition most of the children are regularly examined at welfare clinics and examination of the hip is included in the routine examination at most centres

Fifteen patients with unstable hips at birth were not examined because they had moved from the town It is impossible to say how additional results from examination of this group might have influenced the final results However with the present results in view one can not exclude the possibility that differences between group A and B might be even greater

Of the 146 children with unstable hips at birth eleven received prolonged treatment wiht a plaster cast Seven of them were examined by me As one of the purposes of the present investigation was to study the effect of various factors upon the development of the hip joint it seemed correct to include these patients in the series In the final analyses mean values with and without these patients were compared and there was no differences of the results

The follow up study was performed at four to six years of age This age group was considered suitable for investigation on the following grounds 1 Most children at this age cooperate fairly well and thus permit detailed measurements at both the clinical and radiological examination 2 The development of the hip joint has progressed to such a degree that comparison between different groups of children is possible 3 Practical therapeutic problems often arise in the pre school period so it might be desirable to complete treatment (especially surgical procedures) before the school age

Before embarking on radiological examination of the children of the control group it was necessary to evaluate the risks of x ray studies on healthy individuals (Grossmann 1969 Devil 1971 Frik 1972 Schmidt 1971) Having reviewed the relevant data on the method used in the present investigation I could not find any contraindications to the examination

The radiographic method of Dunlap (Dunlap et al 1953) modified by Rippstein (1955) has the advantage that only two exposures are necessary The described method has been tested by several investigators (Rippstein 1955 Gross 1972) and the conclusion is that it is sufficiently accurate for scientific purposes

The formula used for the correction of the pojected values of the CCD angle and AV angle has been the subject of much discussion Obviously the formula given by Muller (1970) is incorrect (Sudman 1976 Rusten 1976) and the formula used in the present study gives correct values Elsasser (1973) holds that the formula is not precise enough for high values of the AV and CCD angles and that the results may vary by as much as 5 degrees He

uses somewhat different projections and his definition of the AV angle differs from that used in the present study (Gibson 1967 Muller 1970)

The vast literature on the radiological descriptions of the hip gives a strong impression that many variations of both normal and pathological appearances of the joint still remain unexplained Thus there is no unanimous definition of the concept "dysplasia

Various descriptions of the acetabulum include the sloping of the acetabular roof (Hilgenreiner 1925 Idelberger & Frank 1952 Caffey et al 1956 Root 1967 Kalenov 1970 Busse et al 1972) areas of sclerosis (Garavaglia 1970) and the thickness of the bottom of the acetabulum (Schindlmaisser & Kotz 1972) Different measurements have led to a number of concepts such as the Z line (Zsernaviczky 1974) "acetabular head quotient (Sun Do Hong 1969) "Zentrierungs defect (Hoffmann Daimler 1974) Wibergs angle (Wiberg 1939) Fellander et al (1970) points out that it is important to distinguish between late ossification of the acetabular roof with a small or absent lateral margin of the roof and ossification defects as signs of real dysplasia Keller (1973) lists the following important radiological signs of real dysplasia wedge segments delayed ossification of the acetabular roof taillation of the acetabular edge double contour of the acetabulum subchondral sclerosis and steep acetabular roof Among the non osseous signs Garavaglia (1970) describes the arcuate line and the "triangular area" as early signs of dysplasia The upper end of the femur has been described by Hadziselimovic & Secerov (1968) and Skrypczak (1971) among others

Many of the radiological findings can only be demonstrated on specially exposed films and some of the results are difficult to interpret I found the measurements of the present study relatively simple and the results of the measurements suitable for statistical analysis

2 Results

The study of children with unstable hips at birth has shown several deviations from the normal motor development During infancy the following trends were noticed

At three months of age practically all children had an abduction angle of 80–90 degrees The frequency of maximal abduction was reduced to 69 per cent during the second half year of life and remained practically unaltered thereafter

A small group of children (11 patients) showed a gradual increase of passive internal rotation from 40–50 degrees to 80–90 degrees whereas the remainder showed either unaltered or reduced capacity for internal rotation

The number of children with external rotation of 80–90 degrees increased from 30 1 per cent at the age of three months to 93 6 per cent during the second half year of life and then decreased to 69 1 per cent after one year of age

On the basis of investigations made by Harris et al (1960) Haas et al (1973) and Coon et al (1975) the normal internal rotation of the hip is 62 ± 12 9 degrees at birth 26 ± 3 4 degrees at three months and 21 ± 4 3 degrees at six months The external rotation is 89 1 ± 14 3 degrees at birth 45 ± 4 5 degrees at three months and 46 ± 4 8 degrees at six months The normal abduction seems to be 80–90 degrees in the newborn and 60–70 degrees at the age of 1 9 months

As will be discussed later one cannot exclude the possibility that the deviating motor development of children with unstable hips at birth has important influence on the development of the hip joint

It is noteworthy that minor abnormalities of the function of the lower extrem

ities (in toeing when walking, stumbling and complaints of *fatigue*) *appeared* more frequently in the patient group than in the control group.

On the basis of the present investigation the following values seem to represent useful guidelines for evaluation of mobility at the age of four to six years: flexion 130 ± 15 degrees, extension 20 ± 5 degrees, abduction 45 ± 10 degrees, adduction 25 ± 5 degrees, internal rotation in boys 50 ± 15 degrees and in girls 55 ± 15 degrees, external rotation 55 ± 10 degrees.

Clinical examination at the age of four to six years showed several definite differences between the groups A and B. The girls of group A showed on average *a pronounced increase of internal rotation* and a decrease of external rotation of the hip as compared with girls of group B. In conjunction with the radiological findings this is an expression of the increased anteversion of the femoral neck. However, the poor correlation between the clinical and radiological findings (Figure 19) would indicate great caution in the evaluation of increased anteversion of the femoral neck on the basis of clinical examinations only.

The boys of group A had on average an *increased range of passive abduction* movement compared with the boys of group B. No satisfactory explanation for this tendency could be found. In view of the fact that the boys of group A had a decreased range of external rotation but the same range of internal rotation as boys of group B, it is unlikely that the increased abduction ability should depend on increased laxity of the joint. Moreover, one would have expected to *find the same tendency in the group of girls*.

It may be justified to conclude that on average *about 20 per cent of the girls and 10 per cent of the boys of group A showed abnormal function of the hip joint*.

The results of the present study seem to indicate that the following values *might be used* as practical guidelines for the evaluation of X-ray pictures of five to six years old children: AC angle 14 ± 5 degrees, CE angle 31 ± 10 degrees, CCD *angle 135 ± 12 degrees*, AV angle in boys 28 ± 18 degrees, in girls 32 ± 16 degrees. In the absence of comparable studies one cannot be sure that these values apply to other *populations*.

There are few reports of the normal values of the AC angle and CE angle at the age of four to six years. Meyer & Schreiber (1964) give values similar to those of the present study, whereas Tönnis & Brunken (1968), Tönnis (1969) and Tönnis & Trede (1970) give somewhat higher values. The CE values of Wiberg (*1939*) and Severin (*1941*) are similar to ours.

The close correlation between values of the AC angle and the CE angle demonstrated in the present study would indicate that it is sufficient to measure only one of the parameters, preferably the CE angle, which is easier to mate.

The results of the radiological study would indicate that *nearly 30 per cent of the girls and 10 per cent of the boys of group A present clearly pathological values of the angles measured* (2 S.D. or above the mean values).

The results of the present investigation contrast with the normal or nearly normal results of most of the previously reported follow-up investigations (Medbø 1961, Palmén 1961, Barlow 1962, Gregersen 1969, von Rosen 1970, James & Sevastikoglou 1970, *Creze 1970*, Pesch & Ambler 1972, Fredensborg 1976).

Bjerkreim has *stressed the important* fact that even in children where the clinical course has apparently been satisfactory one may find deviation from normal clinical and radiological findings (Bjerkreim 1974). In his large series 24.4 per cent of the children treated with an abduction splint *presented abnormal* signs. Of those, 12 per cent had in

creased anteversion of the femoral neck and 12.4 per cent signs of dysplasia. As Bjerkreim had no control group and did not examine systematically all children treated, some have questioned the reliability of his results (Fredensborg 1976). The results of the present investigation are in agreement with Bjerkreim's findings, the frequency of increased anteversion of the femoral neck being even higher.

The variable results of the different follow-up studies published may be due to one or several of the following factors:

1. Different definitions of the concepts "dysplasia", "preluxation", "instability of the hip", "anteversion of the femoral neck", a.o. (Finlay 1967, Komprda 1974).

2. Lack of standardised diagnostic procedures. The diagnosis of instability of the hip in the newborn period is to some extent subjective. Diagnosis may be missed for such reasons as inexperience, difficult examination (crying child, large baby), dislocated irreducible hips or hips with the potential tendency to dislocate later (Ramstad 1964, Sommer 1971, Uher 1972, Mitchell 1972, Moore 1972). On routine clinical examination of older children minor deviations from the normal may easily be missed. *Lack of standardised radiological examinations and "normal" values of different age groups make it difficult to compare results from different departments.*

3. Congenital dislocation of the hip probably comprises different etiological and pathogenetical entities (Carter & Wilkinson 1964, Wynne-Davies 1970, Wilkinson 1972, Stehr 1972). The genetic background may vary for different populations. The classification of neonatal CDH and late diagnosis CDH which seems widely accepted today may be rather arbitrary. The late diagnosis CDH includes at least three categories of children: a) those who are insufficiently or not examined at birth, b) newborn with stable hips with a potential to dislocate later and c) dislocated irreducible hips. Some investigators would also include patients with unstable hips at birth who are inadequately or not treated.

Apart from the fact that instability of the hip joint at birth may lead in a small proportion of children to luxation, subluxation or dysplasia at a later stage, the true connection between the instability of the hip and late pathological states is unclear.

4. Different long-term results of early treatment of unstable hips may depend on different therapeutic regimes (Allen 1962, Fellander et al. 1970, Lauritzen 1971, Emneus 1971, Ilfeld et al. 1972).

3. *The anteversion of the femoral neck*

Family studies of the structure of the hip do not permit any conclusions concerning a possible genetic influence upon the anteversion of the femoral neck (Carter & Williams 1964, Rott 1969, Wynne-Davies 1970, Czeizel et al. 1975). Getz (1955) found an increased anteversion of the femoral neck in adult Lapps, but this may be due to environmental influence (Bjerkreim 1974). His values for children of 20.5 ± 10.8 degrees are not matched with control subjects.

The embryonal development of the hip joint has been studied by Watanabe (1974). He found great individual variations of the AV angle (– 30 to 40 degrees). In contrast to the other structural characteristics of the hip (neck-shaft angle, depth of the acetabulum and the inclination of the acetabular roof), the AV angle was independent of the age of the foetus. Neither could he find any correlation between the AV angle and the "dysplastic" hip joint which was demonstrated in 9.1 per cent of the cases.

Wilkinson (1963) states that different types of breech malposition may lead to different development of the shape of the femur. The more common lateral rotation breech malposition with flexion of the knees produces femoral retroversion

ities (in toeing when walking stumbling and complaints of fatigue) appeared more frequently in the patient group than in the control group

On the basis of the present investigation the following values seem to represent useful guidelines for evaluation of mobility at the age of four to six years flexion 130 ± 15 degrees extension 20 ± 5 degrees abduction 45 ± 10 degrees adduction 25 ± 5 degrees internal rotation in boys 50 ± 15 degrees and in girls 55 ± 15 degrees external rotation 55 ± 10 degrees

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It may be justified to conclude that on average *about 20 per cent of the girls and 10 per cent of the boys of group A showed abnormal function of the hip joint*

The results of the present study seem to indicate that the following values might be used as practical guidelines for the evaluation of X ray pictures of five to six years old children AC angle 14 ± 8 degrees CE angle 31 ± 10 degrees CCD angle 135 ± 12 degrees AV angle in boys 28 ± 18 degrees in girls 32 ± 16 degrees In the absence of comparable studies one cannot be sure that these values apply to other populations

There are few reports of the normal values of the AC angle and CE angle at the age of four to six years Meyer & Schreiber (1964) give values similar to those of the present study whereas Tonnis & Brunken (1968), Tonnis (1969) and Tonnis & Frede (1970) give somewhat higher values The CE values of Wiberg (1939) and Severin (1941) are similar to ours

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4 *Different long term results of early* treatment of unstable hips may depend on different therapeutic regimes (*Allen* 1962 Fellander et al 1970 Lauritzen 1971 Emneus 1971 Ilfeld et al 1972)

3 *The anteversion of the femoral neck*

Family studies of the structure of *the hip do not permit any conclusions* concerning a possible genetic influence upon the anteversion of the femoral neck (Carter & Williams 1964 Rott 1968 Wynne Davies 1970 Czeizel et al 1975) Getz (1955) found an increased anteversion of the femoral neck in adult Lapps but this may be due to environmental influence (Bjerkreim 1974) His values for children of 20 5 ± 10 8 degrees are not matched with control subjects

The embryonal development of the hip joint has been studied by Watanabe (1974) *He found great individual* variations of the AV angle (— 30 to 40 degrees) In contrast to the other structural characteristics of the hip (neck shaft angle depth of the acetabulum and the *inclination of the acetabular roof*) the AV angle was independent of the age of the foetus Neither could he find any correlation between the AV *angle and the* "dysplastic hip joint which was demon*strated in* 9 1 per cent of the cases

Wilkinson (1963) states that different types of breech malposition may lead to different development *of the shape of the* femur The more common lateral rota*tion breech* malposition with *flexion of* the knees produces femoral retroversion

whereas the medial rotation breech posture leads to femoral anteversion

In the postnatal development of the hip joint both age dependent, sexual and individual variations are well documented The average values of the AV angle of infants are reported to be 30–40 degrees and there seems to be a steady decrease to values of 5–10 degrees in the adult (Dunlap et al 1953 Shands & Steele 1958 Manlot et al 1964 Lenturier & Dechembre 1968 Fabry 1973) This age-dependent decrease of values is also observed in children with an initially pathological increased anteversion (Gibson 1967 Schwarzenbach 1971) Heinrich et al (1968) found a temporary increase of the femoral neck anteversion from 30–40 degrees at birth to 40–50 degrees at the age of four years and a decrease thereafter In the present study the age difference between subjects was relatively small, and the age dependent tendency could not be convincingly demonstrated This justifies the computing of the total number of values of groups A B and C

The normal values given for the AV-angle of children at the age of four to six years differ considerably in the available reports The following figures illustrate some of the diverging results 20 degrees (Shands & Steele 1958) 22 degrees (Dunlap et al 1953) 26 7±7 4 degrees (Fabry 1973) 20–30 degrees (Rogers 1934) 23–40 degrees (Lenturier 1968) 30–50 degrees (Heinrich et al 1968) Different techniques of examination may explain the different results but the influence of different populations cannot be excluded The present findings of 27 5 ± 8 degrees in boys and 31 5 ± 8 degrees in girls are practically the same as those of Fabry However he gives no difference between boys and girls

The present study also demonstrated a correlation between the anteversion of the femoral neck and the build of the child Slender children on average have higher values of the AV angle compared with those of the more athletic type This suggests a possible influence of the muscular activity upon the degree of anteversion

If the muscular influence upon the bony structures is exerted through balanced muscle tone one would not expect to find any correlation between the age of walking start and the values of the AV-angle This assumption was in accordance with the findings of the present study

As early as 1934 Rogers pointed out that various pathological conditions may cause an increase of the anteversion of the femoral neck Among the conditions listed in his report are fractures poliomyelitis osteomyelitis and congenital dislocation of the hip

Cahuzac et al (1974) have shown that cerebral palsy has a valgizing effect on the femur and demonstrated that muscular activity accentuated this effect

Fabry et al (1973) demonstrated increased anteversion of the femoral neck in coxa plana

In the present investigation the highest values for the AV angles (right 67 degrees left 61 degrees) were found in a girl with cerebral palsy (Pat no 71) Another girl (no 31) with a hemiparesis showed increased anteversion of the femoral neck on the same side A girl with polyarthritis (no 17) showed high values of the AV angle (43 degrees)

The association between increased anteversion of the femoral neck and congenital dislocation of the hip has been accepted for several years (Alvik 1962 Gibson 1967 Dalbadie 1971 Fabry 1973 Bjerkreim 1974) In most cases of CDH increased anteversion could also be demonstrated on the unaffected side (Dunlap et al 1953 Shands & Steele 1958 Fabry 1973) The published data seldom give information about the type of congenital dislocation treated but probably most of the patients are of the so called late diagnosis type treated with a plaster

cast or by operation It has not been possible to find any controlled examination of the AV angle of children with unstable hips at birth The present investigation demonstrates that the problem of increased anteversion of the femoral neck exists also in this group of patients

The development of the hip in children of the present series who received prolonged treatment is of special interest Of the eleven patients treated with plaster cast four eventually underwent derotational osteotomy Even if those children were not examined by the same method as used in the present study one must assume that they had considerably increased anteversion of the femoral neck Two patients were checked in the orthopaedic department and had normal findings The remaining five patients are included in the present follow up study Three of them had values of the AV angle 1 ? SD above the mean value and two had normal values except for a difference between the right and left sides of 5 and 7 degrees respectively Thus over 50 per cent of the patients who received prolonged treatment showed increased anteversion of the femoral neck

The relation between increased anteversion of the femoral neck and CDH has been explained by different opposing theories Alvik (1962) regarded the increased anteversion as one of the manifestations of CDH possibly genetically determined Others have regarded the increased anteversion as a secondary phenomenon possibly due to muscular inactivity or special therapeutic procedures (Lettwers 1971 Papadopulos 1971 Somerville 1974) Different theories of pathogenesis for the latter hypothesis have been proposed Lettwers (1971) holds the view that muscular imbalance produces uneven pressure upon the epiphysis and leads to uneven development of the growth of the skeleton Papadopulos (1971) advocates the theory of relative hypertrophy of muscles affecting the rotation movement of the hip

If the sloping acetabular roof with an indistinctly marked lateral margin and a small epiphysis of the femoral head are characteristics of the dysplastic hip (Bjerkreim 1974) it may be noted that no correlation was found between increased anteversion of the femoral neck and dysplastic changes in the present investigation

One of the most important questions is whether abduction splinting may have an untoward influence upon the normal development of the hip joint

As early as 1961 Palmen reported two cases with fragmentation of the femoral head after the ordinary splinting therapy Later similar observations have been made by others (Dabadie 1971) The potential danger of avascular necrosis after abduction splinting has recently been stressed by Mears (1974) but strongly opposed by Fredensborg (1976) Siffert et al (1972) warn against the extreme frog position which produces abnormal pressure on the anterior part of the acetabulum and results in failure of normal development Bjerkreim (1974) states that it is not likely that the pillow treatment is harmful to the hip joint In any case it is justified to conclude that avascular necrosis of the femoral head represents a relatively rare complication However I have not been able to find any controlled investigation of possible other adverse effects of the splinting therapy

The first months of life represent an extremely important period of the child s motor development and it would be surprising if the relative inactivity of the lower extremities in the maximally abducted position should not produce a muscular imbalance with secondary changes in the bony structures Three muscles are important for both abduction and internal rotation of the hip namely gluteus medius gluteus minimus

and the tensor fasciae latea Partial atrophy and shortening of special muscle groups may finally lead to inward rotation of the femur, and the effect may be more marked in individuals with less developed muscles (slender subjects, patients with muscular atrophies of various origin a o)

The possible harmful effect of abduction therapy might be verified by splinting healthy children with stable hips at birth Such a project is however unacceptable on ethical grounds Another approach to the problem is a systematic follow up study of children with unstable hips at birth which are left untreated The group of children examined in the present investigation is too small to allow any definite conclusions but one gains a strong impression that abduction splinting represents at least one of the pathogenetic factors for the increased anteversion of the femoral neck

The beneficial effect of splinting against luxation subluxation and serious dysplastic changes of the hip is undisputable, in spite of the fact that some cases are missed at birth and a certain number do not respond to apparently correct therapy However, in regions where instability of the hip joint appears relatively frequently (Trondheim 22 4 per thousand) the present therapeutic regime possibly leads to pathological development of the hip in 2–4 children per thousand liveborn This number is too high and indicates the necessity of finding more selective criteria of therapy of the newborn

The results of the present investigation have shown an asymmetrical development of the hip joint in a well defined group of children Differences of the AV angle between the right and left hip exceeding 10 were found in 28 per cent in group A and 23 per cent in group B On average the values for the right side were higher than those for the left No certain explanation for these findings can be presented, but the clue to the problem may well be found in the well known habitual oblique position assumed by many infants Palmen (1976) has found the habitual oblique position to be the cause of one sided limited abduction of the hip in about two per cent of infants

Discussion of the indications for derotational osteotomy in cases with increased anteversion of the femoral neck is outside the scope of this project In view of the present investigation one would tend to advocate a more dynamic ' view of the therapy and at least in some patients consider physiotherapy as a possible alternative to operative treatment (Scholder 1967)

SUMMARY

Among 6509 newborn instability of the hip joint was found in 146 (22 4 per thousand liveborns) All of them were treated with Frejka cusion splint usually for three months Eleven patients required additional treatment with a plaster cast, and in four a derotational osteotomy was performed

During infancy the children showed several deviations from the normal motor development the most important being an increased abduction and an increased external rotation capacity of the hip joint A small group of infants showed a gradual increase of the passive internal rotation from 40–50 degrees to 80–90 degrees

In 129 patients a detailed clinical and radiological follow up study was performed at the age of four to six years and the results were compared with those of 100 healthy children and 17 children with unstable hips at birth left untreated

Clinical examination at the age of four to six years showed that about 20 per cent of the girls and about 10 per cent of the boys with unstable hips treated with abduction had abnormal function of the hip The most important findings were

increased internal rotation and decreased external rotation in girls and increased abduction in boys

Radiological examination of the treated group of affected children showed pathological values of the angles measured in 30 per cent of the girls and in 10 per cent of the boys *In girls pathological mean* values were demonstrated for all angles measured (AC CE CCD and AV) whereas the boys displayed pathological values of the AV angle only

The mean angle values of the untreated children with unstable hips at birth showed no significant deviation from the values of the control group

A positive correlation was demonstrated between the values of the AC-angle and the CE-angle but no correlation could be demonstrated between the AVangle and the other angles

Slender children showed significantly higher values *for the AV angle* than children with a low height/weight ratio

Seven of eleven children who received prolonged treatment with a plaster cast *showed pronounced anteversion of* the femoral neck Increased anteversion of the femoral neck was also demonstrated in three patients with concomitant muscular abnormalities

It is suggested that increased anteversion of the femoral neck is a secondary phenomenon in CDH possibly because of relative muscular inactivity and that abduction *splintage may be a causative* factor

APPENDIX

Results of the radiological examination of 129 children with unstable hips at birth treated with an abduction splint (group A) 100 healthy children (group B) and 17 children with unstable hips at birth left untreated (group C) The excluded numbers represent subjects not followed up

GROUP A

Case no	Name	AC angle R	AC angle L	CL angle R	CL angle L	CCD angle R	CCD angle L	AV angle R	AV angle L
1	Au	10	10	34	34	138	140	63	62
2	Sa	20	20	32	32	139	133	59	60
3	Lo	15	15	32	32	133	131	35	40
5	Od	13	13	35	40	133	133	35	35
6	Du	10	10	36	38	135	135	36	35
7	Gj	20	18	25	29	143	143	34	34
8	Pr	18	16	26	29	139	139	47	47
9	Kn	12	12	31	38	131	127	35	34
10	St	18	18	27	27	130	138	29	25
11	Da	12	12	32	36	132	130	35	26
12	Fu	5	8	39	39	143	143	35	35
14	Pe	8	10	40	34	142	140	53	56
15	Br	15	15	25	25	135	135	38	37
16	Un	15	15	27	27	125	126	38	36
17	Ve	13	13	25	30	146	146	43	43
18	Ha	14	14	30	30	133	135	33	36
19	Tø	13	10	32	35	126	126	33	24
20	To	16	18	30	27	130	130	42	42
21	Ia	17	17	30	30	133	122	41	36
22	Ru	10	12	32	32	129	129	35	33
23	Sn	6	3	32	33	136	132	41	26
24	No	21	24	23	23	139	138	49	45
25	Mø	15	15	27	27	134	132	45	58
26	Bu	10	8	36	36	127	128	35	37
27	Fr	13	12	30	30	145	145	24	24
28	Sc	17	17	30	34	140	137	38	25
30	Am	17	17	30	30	129	129	28	48
31	So	15	21	20	20	140	147	17	23
32	Ni	18	18	30	30	143	143	40	40
33	Sk	19	19	27	25	146	148	43	40
35	Hø	12	12	33	33	128	128	30	30
36	Bu	13	13	40	40	132	13[illegible]	41	41
37	Jo	18	18	25	25	128	131	46	38
38	Kn	8	8	37	37	130	128	39	38
39	Da	12	12	28	28	140	[illegible]	26	26
40	Sæ	15	15	32	33	137	135	41	37
41	Sø	10	15	31	28	134	134	34	34
42	Br	13	13	31	31	137	135	33	28
44	Tr	18	18	25	29	137	137	39	43
45	We	14	14	30	30	135	138	40	40
46	El	12	12	40	35	140	143	40	[illegible]
47	No	14	8	31	41	131	134	32	29
48	Ha	18	18	31	31	141	146	62	56
49	Pe	20	20	27	27	141	141	41	41
50	Wi	18	18	30	32	145	143	5[illegible]	47

APPENDIX (continued)

GROUP A

Case no	Case Name	AC angle R	AC angle L	CE angle R	CE angle L	CCD angle R	CCD angle L	AV angle R	AV angle L
51	Ra	10	8	33	33	137	137	30	35
52	Be	20	20	30	30	130	134	48	38
54	St	14	18	30	30	152	146	50	53
57	Fo	12	10	32	37	132	129	33	27
58	Sk	10	10	35	35	147	146	32	24
59	Fr	20	17	26	28	140	142	30	23
60	Re	14	14	30	30	147	147	35	36
61	Ha	18	18	25	30	128	126	54	38
62	Rl	13	13	24	31	135	137	40	27
63	Je	9	9	40	40	134	133	34	35
64	St	12	12	31	31	143	143	40	40
65	St	15	15	30	30	145	152	48	54
66	Bo	13	13	32	32	151	147	44	37
67	Nj	10	10	35	35	126	127	43	35
69	So	20	20	25	5	135	133	35	30
0	Sæ	15	15	27	32	130	131	36	33
71	Ne	25	25	16	24	151	154	67	61
72	Qu	16	16	29	29	135	135	31	30
73	Sv	15	15	30	34	135	136	22	17
74	Mu	15	15	35	35	137	136	43	46
5	Re	15	15	0	20	141	140	41	30
77	Ne	12	12	29	29	144	141	31	38
8	Sl	30	23	14	9	134	146	29	6
9	W	18	18	25	30	134	131	33	30
80	La	13	13	30	30	132	143	46	40
81	An	16	16	27	9	147	146	47	41
82	St	16	16	30	30	142	141	41	39
83	Do	15	15	29	35	136	134	41	45
85	Wa	15	15	30	32	132	144	39	32
87	Lo	13	13	36	36	131	131	21	22
88	Sk	18	15	33	31	133	129	34	33
89	Ta	11	11	31	31	142	142	51	51
90	Pa	15	15	31	31	140	135	42	40
92	So	0	0	3	23	139	142	33	36
93	Ho	14	14	30	40	142	145	26	33
94	Es	18	18	23	6	135	134	31	33
95	Ka	12	12	25	25	139	135	49	53
96	Hk	15	13	34	34	126	123	50	43
97	Sl		18	27	32	132	126	45	27
93	Da	15	15	33	35	1 8	124	36	30
99	Ol	5	2	20	20	139	138	35	30
100	Ol	13	13	30	30	135	133	33	34
101	Cr	10	13	40	40	141	140	49	42
102	Pe	23	3	5	22	137	133	41	39
104	Ho	13	13	35	35	137	133	37	32
10	Jo	10	10	36	36	143	143	36	36
106	Af	15	15	33	37	129	1 9	49	49
107	Jo	15	15	28	30	143	143	32	47
108	HJ	15	15	34	34	133	133	39	39
109	Cr	15	15	30	30	148	148	37	37
110	Ha	15	13	32	37	137	134	39	38
111	Cr	14	14	30	30	133	136	43	41

APPENDIX

Results of the radiological examination of 129 children with unstable hips at birth treated with an abduction splint (group A) 100 healthy children (group B) and 17 children with unstable hips at birth left untreated (group C) The exluded numbers represent subjects not followed up

GROUP A

	Case	AC angle		CE angle		CCD angle		AV angle	
no	Name	R	L	R	L	R	L	R	L
1	Au	10	10	34	34	138	140	63	67
2	Sa	20	20	32	32	139	139	59	60
3	Fo	15	15	32	32	133	131	35	40
5	Od	13	13	35	40	133	133	35	35
6	Du	10	10	36	38	135	135	36	35
7	Gj	20	18	25	29	143	143	34	34
8	Pr	18	16	26	29	139	139	47	47
9	Kn	12	12	31	38	131	127	35	24
10	St	18	18	27	27	130	138	29	25
11	Da	12	12	32	36	132	130	35	26
12	Fu	5	8	39	39	143	143	35	35
14	Pe	8	10	40	34	142	140	53	56
15	Br	15	15	45	25	135	135	38	32
16	Un	15	15	27	27	125	126	38	36
17	Ve	13	13	25	30	146	146	43	43
18	Ha	14	14	30	30	133	135	33	36
19	Tø	13	10	32	35	126	126	33	24
20	To	16	18	30	27	130	130	42	42
21	Aa	17	17	30	30	133	122	41	36
22	Ru	10	12	32	32	129	129	35	39
23	Sn	6	3	32	39	136	132	41	26
24	No	21	24	23	23	139	138	49	45
25	Mø	16	15	27	27	134	132	45	50
26	Bu	10	8	36	36	127	128	35	32
27	Er	12	12	30	30	145	145	24	24
28	Sc	17	17	30	34	140	137	38	25
30	Am	17	17	30	30	129	129	28	28
31	So	15	21	20	20	140	147	17	23
32	Ni	18	18	30	30	143	143	40	40
33	Sk	19	19	27	25	146	148	43	40
35	Hø	12	12	33	33	128	129	30	30
36	Bu	13	13	40	40	132	132	41	41
37	Jo	18	18	25	25	128	131	46	38
38	Kn	8	8	37	37	130	128	39	38
39	Da	12	12	28	28	140	140	26	26
40	Se	15	15	32	33	137	135	41	37
41	Sø	10	15	31	28	134	134	34	34
42	Br	13	13	31	31	137	135	33	29
44	Tr	18	18	29	29	137	137	39	43
45	We	14	14	30	30	135	138	40	40
46	El	12	12	40	35	140	143	30	25
47	No	14	8	31	41	131	134	32	29
48	Ha	18	18	31	31	141	146	62	56
49	Pe	20	20	27	27	141	141	41	41
50	Wi	18	18	30	32	145	143	55	47

APPENDIX (continued)

GROUP A

Case no	Case Name	AC-angle R	AC-angle L	CE-angle R	CE-angle L	CCD angle R	CCD angle L	AV angle R	AV angle L
51	Rø	10	8	33	33	137	137	30	35
52	Be	20	20	30	30	130	134	48	38
54	St	14	18	30	30	152	146	50	53
57	Fo	12	10	32	37	132	129	33	27
58	Sk	10	10	35	35	147	146	32	24
59	Fr	20	17	26	23	140	142	30	23
60	Re	14	14	30	30	147	147	35	36
61	Ha	18	18	25	30	128	126	54	38
62	Ri	13	13	24	31	135	137	40	27
63	Je	9	9	40	40	134	133	34	35
64	St	12	12	31	31	143	143	40	40
65	St	15	15	30	30	145	152	48	54
66	Bo	13	13	32	32	151	147	44	37
67	Nj	10	10	35	35	126	127	43	35
69	So	20	0	25	25	135	133	35	30
70	Sæ	15	15	27	32	130	131	36	33
71	Ne	25	25	16	24	151	154	67	61
72	Qu	16	16	29	29	135	135	31	30
73	Sv	15	15	30	34	135	136	22	17
74	Mu	15	15	35	35	137	136	43	46
75	Rø	15	15	20	20	141	140	41	30
77	Ne	12	12	29	29	144	141	31	38
78	Sl	30	23	14	9	134	146	29	6
79	We	18	18	25	30	134	131	33	30
80	La	13	13	30	30	132	143	46	40
81	An	16	16	27	29	147	146	47	41
82	St	16	16	30	30	142	141	41	39
83	Do	15	15	29	35	136	134	41	45
85	Wa	15	15	30	32	132	144	39	32
87	Lo	13	13	36	36	131	131	21	22
88	Sk	18	15	33	31	133	129	34	33
89	Ta	11	11	31	31	142	142	51	51
90	Pa	15	15	31	31	140	135	42	40
92	S	20	20	23	23	139	142	33	36
93	Rø	14	14	30	40	142	145	26	33
94	Es	18	18	23	26	135	134	31	33
95	Ka	12	12	25	2	139	135	49	53
96	HÅ	1	13	34	34	126	123	50	43
97	Sl	22	18	27	32	132	126	45	27
98	Da	15	15	33	35	128	124	36	30
99	Ol	25	25	20	20	139	138	35	30
100	Ol	13	13	30	30	135	133	33	34
101	Gr	10	13	40	40	141	140	49	42
102	Le	23	4	25	22	137	133	41	39
104	Ho	13	13	35	35	137	133	37	32
105	Jo	10	10	36	36	143	143	36	36
106	Af	15	15	33	37	129	129	49	49
107	Jo	15	15	28	30	143	143	32	47
108	Hj	15	15	34	34	133	133	39	39
109	Gr	15	15	30	30	148	148	37	37
110	Ha	15	13	32	37	137	134	39	38
111	Gr	14	14	30	30	133	136	43	41

APPENDIX (continued)

GROUP A

	Case	AC angle		Cl angle		CCD angle		AA angle	
no	Name	R	I	R	I	R	I	R	I
113	Aa	14	14	33	35	137	137	42	42
114	Kr	20	20	[illegible]	30	129	126	44	43
115	Al	17	17	26	26	137	137	26	26
116	Aa	20	20	21	25	136	136	44	43
117	Sj	19	19	21	25	136	138	34	34
118	To	18	18	30	35	135	138	50	50
119	Ma	15	10	30	35	143	141	53	44
120	Ma	15	15	31	35	127	129	46	46
121	Ne	18	18	[illegible]	30	137	137	33	33
122	Ni	19	19	27	24	135	136	27	22
123	Ro	10	14	35	33	134	134	33	37
124	Ho	18	18	28	30	137	129	39	33
125	Os	16	18	26	27	131	132	23	25
126	As	17	17	26	26	137	139	32	33
127	Is	15	12	33	40	148	136	40	35
128	Ej	14	14	32	30	141	139	33	51
129	Be	20	20	22	24	134	134	39	39
130	Gj	17	15	25	30	139	141	32	38
131	Ni	14	14	37	[illegible]	129	128	39	36
132	La	17	17	25	25	141	142	45	30
133	Mj	13	13	32	32	131	133	29	28
134	Na	10	15	30	23	133	129	45	40
135	Gr	23	23	25	25	139	133	45	39
137	Sa	20	18	27	27	156	148	48	42
138	Hu	17	17	24	28	134	138	25	38
139	Gr	17	17	35	32	124	124	28	28
140	Le	37	21	10	21	120	150	5	9
141	Pe	15	13	30	32	133	134	43	42
142	Ny	17	19	30	30	134	130	27	11
143	Lr	20	20	25	25	134	130	36	45
145	Te	17	13	33	35	135	134	45	34
146	Sk	20	22	25	27	132	139	30	35

APPENDIX (continued)

GROUP B

Case no	Case Name	AC-angle R	AC-angle L	CE angle R	CE angle L	CCD angle R	CCD angle L	AV angle R	AV angle L
379	Si	20	20	29	27	133	134	35	33
380	*Ge*	7	7	40	42	129	129	30	30
382	Sa	15	18	27	27	135	136	14	16
383	Su	15	15	25	30	127	126	30	32
385	Be	12	12	27	34	143	138	39	37
88	Næ	17	15	25	25	137	137	23	21
389	Ag	15	12	25	27	136	137	30	29
390	Ca	17	17	27	32	138	139	38	31
391	Th	10	10	33	37	122	124	29	32
393	Cr	10	10	35	35	127	127	28	26
394	Ky	13	13	39	39	123	124	33	29
395	Su	15	12	27	27	131	128	22	19
396	Sk	19	19	24	22	130	131	36	37
399	*Rø*	9	9	31	34	135	135	27	27
401	Wo	15	15	30	36	130	128	34	22
402	An	8	8	38	38	126	123	36	35
406	*Gr*	18	17	21	24	141	139	33	33
407	He	20	20	20	22	139	139	41	36
408	My	8	8	35	38	149	147	19	18
409	Me	12	12	35	35	129	133	28	25
411	Ha	10	13	31	31	143	142	36	39
41	Ki	13	13	27	33	131	134	23	29
413	Gj	11	15	30	27	135	133	23	49
414	Si	15	13	29	32	155	147	29	19
415	Ny	10	12	35	38	145	146	27	23
419	Mj	24	24	15	17	131	130	40	32
420	Mo	20	18	26	26	146	147	45	45
421	Ro	10	10	37	37	134	132	29	25
423	Sø	14	14	35	34	141	137	22	23
424	Lu	12	12	31	35	126	125	41	33
425	Gr	15	15	30	30	129	133	17	16
426	Le	14	13	35	35	134	134	36	36
430	Er	10	10	40	41	124	132	43	36
431	Lu	12	12	36	36	123	124	26	34
432	Ha	25	25	18	18	142	141	23	19
433	Be	12	12	36	31	125	134	32	11
43	Be	15	15	31	28	138	136	38	40
438	Jo	20	16	33	38	141	132	25	34
440	Ja	13	13	30	35	136	136	21	22
441	Ma	15	15	30	30	145	145	36	36
442	Ha	12	12	35	35	136	137	19	25
447	Sv	13	15	41	38	142	138	43	45
448	*Ha*	13	18	30	30	129	129	43	44
449	Ku	13	13	25	30	135	135	45	45
450	Ha	13	13	35	30	145	148	38	40
451	Ye	10	10	35	38	144	144	33	25
4 3	Ha	10	12	40	40	131	130	42	51
455	Rø	18	18	33	33	131	133	21	23
456	Ma	12	12	35	38	139	139	36	36
457	Vo	19	14	30	35	138	130	36	28
458	*Hå*	10	12	44	40	132	131	44	37
460	Fe	10	14	35	2	135	137	22	35

APPENDIX (continued)

GROUP B

Case		AC angle		CI angle		CCD angle		AX angle	
no	Name	R	L	R	L	R	L	R	L
462	Wo	17	19	30	30	139	142	50	48
463	Se	8	10	38	40	130	130	36	44
464	Re	15	10	30	30	131	128	27	33
465	Gj	17	15	25	30	140	136	36	[illegible]
468	Hå	10	10	32	36	139	140	32	[illegible]7
470	Ru	15	15	26	30	137	134	34	36
471	Hå	12	12	32	36	132	133	26	[illegible]9
473	Sl	10	10	35	37	135	135	44	4[illegible]
474	Wo	13	13	31	29	142	143	37	31
475	Kv	13	13	33	37	124	122	37	37
476	Mo	15	15	34	35	138	139	29	2[illegible]
479	Bj	13	13	33	33	138	140	32	27
480	St	10	10	35	38	128	129	[illegible]2	22
481	Mc	15	15	33	33	142	139	48	47
482	La	13	13	30	30	135	135	23	[illegible]2
483	Tr	15	15	30	33	139	138	37	[illegible]4
485	Ny	8	8	42	44	126	125	33	30
486	Jo	14	14	32	30	138	139	29	33
487	Ia	22	22	26	23	138	136	34	39
488	Ka	13	13	32	32	129	129	21	[illegible]1
489	Aa	13	13	36	36	134	135	43	44
491	Ha	12	17	35	30	135	135	40	40
492	Tl	15	15	30	30	133	133	21	21
493	Tr	13	13	35	35	134	134	16	16
494	Ha	18	15	25	30	133	137	25	[illegible]9
496	Kv	15	11	31	39	133	134	28	[illegible]
497	Be	18	18	28	30	129	129	26	26
498	Wo	15	15	28	30	136	133	22	21
499	Bj	12	12	30	32	130	130	33	33
500	Be	8	8	32	34	146	146	42	39
502	No	15	1[illegible]	30	32	132	132	26	[illegible]4
503	Ul	17	17	29	26	147	149	29	30
504	Iu	15	15	35	32	127	127	20	22
505	Sl	15	18	28	30	120	121	34	32
506	Ha	13	13	33	35	132	132	34	31
507	No	15	15	30	30	137	134	21	19
508	St	18	18	25	28	135	135	33	33
509	He	12	12	35	35	146	146	23	22
510	Sv	10	10	34	34	119	119	23	27
513	Ha	13	13	30	33	130	130	37	3[illegible]
514	Bu	15	15	31	31	131	131	30	33
515	Go	12	12	30	32	123	125	17	19
516	Pa	17	17	27	27	138	135	36	28
518	Be	19	19	26	30	140	140	47	46
519	Jo	13	13	38	40	128	1[illegible]8	40	40
520	La	12	12	33	33	133	136	30	31
523	Ir	12	12	29	29	132	134	[illegible]9	30
524	Sn	15	15	[illegible]9	31	137	143	42	36

APPENDIX (continued)

GROUP C

Case no	Case Name	AC angle R	AC angle L	CE-angle R	CE-angle L	CCD angle R	CCD angle L	AV angle R	AV angle L
757	An	15	15	33	33	121	121	29	29
758	Su	12	12	30	35	144	144	50	37
761	An	10	10	36	40	128	128	31	28
762	Re	13	15	37	30	129	130	26	35
763	Pe	12	12	30	35	132	129	26	24
764	Ci	15	15	33	34	129	129	28	34
765	Tø	13	13	31	3?	138	142	33	37
766	Bi	12	10	38	8	132	131	29	32
767	Pe	10	7	33	42	1?7	125	35	31
768	To	?2	22	23	23	130	127	36	32
769	Jo	15	15	31	34	1?8	126	36	30
770	Gå	12	12	36	33	126	128	39	45
771	Re	17	17	29	26	143	141	50	45
773	Ha	18	15	33	35	133	128	43	36
776	He	10	10	35	45	135	132	41	47
777	Gu	20	20	30	34	135	130	?6	22
778	Ri	7	7	38	38	136	133	26	19

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REFERENCES

Ackermann H J (1970) Unsere Erfahrungen bei der systematischen Untersuchung der Hüftgelenke von Neugeborenen *Beitr Orthop Traum* **17** 133–134

Ackermann H J Knauf G & Rudolph F (1974) Siebenjährige Erfahrungen mit organisierten Neugeborenenuntersuchungen zur Früherstererfassung und therapie der Luxationshüfte *Beitr Orthop Traum* 21 624–633

Allen R P (1962) Ischemic necrosis following treatment of hip dysplasia *J Amer med Ass* **180** 497–499

Alvik I (1959) Den medfødte hofteleddsdysplasi *T norske Lægeforen* 79 7–8

Alvik I (1962) Increased anteversion of the femur as the only manifestation of dysplasia of the hip *Clin Orthop* 22 16–20

Andren L (1960) Instability of the pubic symphysis and congenital dislocation of the hip in the newborn *Acta radiol (Stockh)* **54** 123–128

Andrén L & Palmén K (1963) Seasonal variations of birth dates of infants with congenital dislocation of the hip *Acta orthop scand* 33 127–131

Artz T D, Levine D B, Lim W N Salvati E A & Wilson P D (1975) Neonatal diagnosis treatment and related factors of congenital dislocation of the hip *Clin Orthop* **110** 112–136

Barlow T G (1962) Early diagnosis and treatment of congenital dislocation of the hip *J Bone Jt Surg* 44 B 292–301

Barlow T G (1963) Early diagnosis and treatment of congenital dislocation of the hip *Proc roy Soc Med* 9 804–806

Bjerkreim I (1974) Congenital dislocation of the hip joint in Norway *Acta orthop scand* Suppl 157

Brattstrom H (1962) Two sources of error in measurement of the anteversion angle of the femur *Acta orthop scand* 32 252–256

Busse J Gasteiger W & Tonnis D (1972) Eine neue Methode zur rontgenologischer Beurteilung eines Hüftgelenkes – Der Hüftwert *Arch orthop Unfall Chir* 72 1–9

Caffey J Ames R Silverman W A Ryder C T & Hough G (1956) Contradiction of the congenital dysplasia predislocation hypothesis of congenital dislocation of the hip through a study of the normal variations in the acetabular angles at successive periods of infancy *Pediatrics* 17 632–640

Cahuzac M, Ousset A Alauze C & Cleverie et Michil P (1974) La hanche de l enfant I M C apres 2 ans *Rev Chir Orthop* Suppl 2 253 258

Carter C O & Wilkinson J A (1964) Genetic and environmental factors in the etiology of congenital dislocation of the hip *Clin orthop* 33 119–128

Carter C O & Wilkinson J A (1964) Persistent joint laxity and congenital dislocation of the hip *J Bone Jt Surg* 46 B 40–45

Chapple C C (1935) Congenital dislocation of the hip in infancy *J Pediat* 6 306–315

Chen R Weissmann S I Salama R & Klingberg M A (1970) Congenital dislocation of the hip (CDH) and seasonality the gestational age of vulnerability to some seasonal factor *Am J Epidemiol* 92 287–293

Coon V Donato G Houser C & Bleck E I (1975) Normal ranges of hip motion in infants six weeks three months and six months of age *Clin orthop* 110 256–260

Crézé M J (1970) Résultat de la recherche systematique de signe de Le Damany (dit signe d Ortolani) de 1963 à 1970 *Bull Féd Soc Gynéc Obstét franç* 23 663–664

Czeizel A Szentpétery J Tusnády G & Vizkelety T (1975) Two family studies on congenital dislocation of the hip after early orthopedic screening in Hungary *J Med Genet* 12 125–130

Czeizel A Tusnády G Vaczo G & Vizkelety T (1975) The mechanism of genetic predisposition in congenital dislocation of the hip *J Med Genet* 12 121–124

Dabadie J (1971) Résultat de 6 ans de dépistage et de traitement préventif de la luxation congénitale de la hanche *Ann Chir Inf* 12 147–158

Devik F (1971) Hensyn og begrensninger ved bruk av radioaktive nuklider i klinisk forskning *T norske Lægeforen* 91 2564–2568

Dunlap K Hollister I C & Streit H A (1953) A new method for determination of torsion of the femur *J Bone Jt Surg* 35 289–311

Dunn D M. (1952) Anteversion of the neck of the femur A method of measurement *J Bone Jt Surg* 34-B 181-186

Elsasser U & Walker N (1973) Zur Bestimmung der Torsion des Schenkelhalses *Z Orthop* 111, 926-933

Emmeus H & Undeland K (1971) A 4 year pro pective study of two different therapeutic regiments for newborn with CDH. *Acta orthop scand* 42 457

Eriksson U, James, U & Wikstrom G (1970) The angle of anteversion and the neck shaft angle in children—a roentgenological and clinical study *Acta Soc Med Ups* 75 229-240

Fabry G McEwen G D & Shands A R (1973) Torsion of the femur A follow up study in normal and abnormal conditions *J Bone Jt Surg* 55-A 1726-1738

Fellander M Gladnikoff H & Jacobsson E (1970) Instability of the hip in the newborn Classification for selective treatment pathogenesis of the dislocation and complications *Acta orthop scand* Suppl 130 36-54

Fettweis F (1971) Die Wirkung der Spreizbehandlung auf den Schenkelhalswinkel (CCD Winkel) kindlicher Huftgelenke *Z Orthop* 109 735-736

Fettweis E (1973) Das Huftluxationsleiden bei in Beckenlage geborenen Kindern Zur Pathogenese und Bedeutung fur das Luxationsproblem *Z Orthop* 111 168-178

Finlay H V L Maudsley R H & Busfield P I (1967) Dislocatable hip and dislocated hip in the newborn infant *Brit med J* 4 377-381

Fisher R L Scott Duncan A & Bronzino J D (1972) The application of axial transverse tomography to the measurement of femoral anteversion *Clin Orthop* 86 6-12

Fredensborg N (1976) The effect of early diagnosis of congenital dislocation of the hip *Acta Paediat Scand* 65 323-328

Frejka B (1941) Praventation der angeborenen Huftgelenkluxation durch das Abductionspolster *Wien med Wschr* 91, 523-524

Frik W (1972) Reihenuntersuchungen der Huftgelenke bei Sauglingen und Strahlenschutz Ein Gutachten der Deutschen Rontgengesellschaft *Fortschr Röntgenstr* 116 4 453-455

Garavaglia, C. (1970) Early diagnosis of congenital dyspla ia of the hip New roentgenological sign *Am J Roentgenol Radium Th r Nucl Med* 110 587-90

Getz B (1955) The hip joint and its bearing on the problem of congenital dislocation *Acta orthop* and Suppl 18

Gibson R D (1967) Anteversion of the femoral neck A m thod of measurement *Australas Rad ol* 11 163-169

Gross F (1972) Die röntgenol gische Bestimmung der Antetorsion des koxalen Femurendes nach Rippstein – Genauigkeit und Fehlquellen *Z Orthop* 110 998-1005

Grossmann H (1969) Die Bedeutung der Rontgendiagnostik fur die Fruherkennung der Huftgelenkluxation *Kinderarztl Prax* 37 1-7

Haas S S., Epps, C H & Adams J P (1973) Normal ranges of hip motions in the new born *Clin Orthop* 91, 114-118

Haberler von G (1944) Neue Erkentnisse der angeborenen Huftgelenkverrenkung und ihrer Behandlung *Z Orthop* 75 38-59

Hadziselimović H & Šećerov D (1968) Appearance of the upper end of the femur in infants under normal conditions and in cases of dislocation *Acta anat (Basel)* 70 509-523

Harlem O K. (1961) Medfødt hofteleddsdysplasi *Nord Med* 66 1277

Harris L F & Hodgson J R (1960) Hilgenreiner measurements of the hip roentgenogram in 247 normal infants 6 and 7 months of age *J Pediat* 56 478-484

Harris L E Lipscomb P R & Hodgson J R (1960) Early diagnosis of congenital dysplasia of the hip *J amer med Ass* 173 229 233

Hart V L (1949) Congenital dysplasia of the hip joint *J Bone Jt Surg* 31 A 357-372

Heinrich R Hennig A & Thiel K W (1968) Rontgenologische Untersuchung zur umwegigen Entwicklung der Femurtorsion bei huftgesunden Kindern *Z Orthop* 104 555-61

Hilgenreiner H (1925) Zur Fruhdiagnose und Fruhbehandlung der angeborenen Huftgelenkverrenkung *Med Klin* 37 1385-1425

Hilgenreiner H (1925) Zur Fruhdiagnose und Fruhbehandlung der angeborenen Huftgelenkverrenkung *Med Klin* 37 1425-1429

Hirsch C & Scheller S (1969) Result of treatment from birth of unstable hips A clinical and radiological 5 year follow up *Clin Orthop* 62 162-166

Hirsch, C. & Scheller S (1970) Result of treatment from birth of unstable hips *Acta orthop scand* Suppl 130 25-29

Hoffmann Daimler S (1974) Zentrierungsdefizit" am Huftgelenk *Z Orthop* 112 502-506

Huttová M Rusnák M., Stefániková J & Požtolka I (1972) Výsledky použitia abdukcného balenia od narodenia u deti s dysplaziou bedrových klbov *Cs Pediat* 27 541-544

Hayer S E. (1975) Personal communication

Idelberger K & Frank, A (1952) Uber eine neue Methode zur Bestimmung des Pfannendachswinkels beim Jugendlichen und Erwachsenen *Z Orthop* 82 571-577

Ilfeld F W., O Hara J., Robins G., Westin J R

REFERENCES

Ackermann H J (1970) Unsere Erfahrungen bei der systematischen Untersuchung der Huftgelenke von Neugeborenen *Beitr Orthop Traum* 17 133–134

Ackermann H J Knauf C & Rudolph F (1974) Siebenjahrige Erfahrungen mit organisierten Neugeborenenuntersuchungen zur Fruherfassung und therapie der Luxationshüfte *Beitr Orthop Traum* 21 624–633

Allen R P (1962) Ischemic necrosis following treatment of hip dysplasia *J Amer med Ass* 180 497–499

Alvik I (1959) Den medfødte hofteleddsdysplasi *T norske Lægeforen* 79 7–8

Alvik I (1962) Increased anteversion of the femur as the only manifestation of dysplasia of the hip *Clin Orthop* 22 16–20

Andrén L (1960) Instability of the pubic symphysis and congenital dislocation of the hip in the newborn *Acta radiol (Stockh)* 54 123–128

Andrén L & Palmén K (1963) Seasonal variations of birth dates of infants with congenital dislocation of the hip *Acta orthop scand* 33 127–131

Artz T D Levine D B Lim W N Salvati E A & Wilson P D (1975) Neonatal diagnosis treatment and related factors of congenital dislocation of the hip *Clin Orthop* 110 112–136

Barlow T G (1962) Early diagnosis and treatment of congenital dislocation of the hip *J Bone Jt Surg* 44 B 292–301

Barlow T G (1963) Early diagnosis and treatment of congenital dislocation of the hip *Proc roy Soc Med* 9 804–806

Bjerkreim I (1974) Congenital dislocation of the hip joint in Norway *Acta orthop scand* Suppl 157

Brattstrom H (1962) Two sources of error in measurement of the anteversion angle of the femur *Acta orthop scand* 32 252–256

Busse J Gasteiger W & Tonnis D (1972) Eine neue Methode zur rontgenologischer Beurteilung eines Hüftgelenkes – Der Hüftwert *Arch orthop Unfall Chir* 72 1–9

Caffey J Ames R Silverman W A Ryder C T & Hough G (1956) Contradiction of the congenital dysplasia predislocation hypothesis of congenital dislocation of the hip through a study of the normal variations in the acetabular angles at successive periods of infancy *Pediatrics* 17 632–640

Cahuzac M Ousset, A Mauze C & Cleverie et Nichil P (1974) La hanche de l enfant I M C. après 2 ans *Rev Chir Orthop* Suppl 2 253 258

Carter C O & Wilkinson J A (1964) Genetic and environmental factors in the etiology of congenital dislocation of the hip *Clin orthop* 33 119–128

Carter C O & Wilkinson J A (1964) Persistent joint laxity and congenital dislocation of the hip *J Bone Jt Surg* 46 B 40–45

Chapple C C (1935) Congenital dislocation of the hip in infancy *J Pediat* 6 306–315

Chen R Weissmann S L Salama R & Klingberg M A (1970) Congenital dislocation of the hip (CDH) and seasonality the gestational age of vulnerability to some seasonal factor *Am J Epidemiol* 92 287–293

Coon V Donato G Houser C & Bleck E E (1975) Normal ranges of hip motion in infants six weeks three months and six months of age *Clin orthop* 110 256–260

Crézé M J (1970) Résultat de la recherche systematique de signe de Le Damany (dit signe d Ortolani) de 1963 à 1970 *Bull Féd Soc Gynec Obstét franç* 23 663–664

Czeizel A Szentpétery J Tusnády G & Vizkelety T (1975) Two family studies on congenital dislocation of the hip after early orthopedic screening in Hungary *J Med Genet* 12 125–130

Czeizel A Tusnády G Vaczo G & Vizkelety T (1975) The mechanism of genetic predisposition in congenital dislocation of the hip *J Med Genet* 12 121–124

Dabadie J (1971) Résultat de 6 ans de dépistage et de traitement préventif de la luxation congénitale de la hanche *Ann Chir Inf* 12 147–158

Devil F (1971) Hensyn og begrensninger ved bruk av radioaktive nuklider i klinisk forskning *T norske Lægeforen* 91 2564–2568

Dunlap K Hollister I C & Streit H A (1953) A new method for determination of torsion of the femur *J Bone Jt Surg* 35 289–311

Rogers R S (1934) Observations on torsion of the femur *J Bone Jt Surg* 16 284–289

von Rosen S (1970) Instability of the hip in the newborn *Fifteen years experience in Malmo Acta orthop scand* Suppl. 130 1–24

Rosenthum, H Ramsey P & McEwen G D (1972) Congenital hip dislocation *Delaware med J* 44 113

Rott Z (1967) Der CE Winkel (Wiberg) und seine Messung *Z Orthop* 102 461–463

Rott Z (1968) Rontgenologische Untersuchung von Familien mit Vodkommen von angeborenen Huftverrenkung *Z Orthop* 104 181–196

Rusten P (1976) Personal communication

Severin E (1941) Contribution to the knowledge of congenital dislocation of the hip joint. *Acta chir scand* Suppl. 63 1–142

Schmidt H (19 4) *Uber das Fur und Wider von* Rontgenreihenuntersuchungen zur Fruher kennung der Luxationshufte bei Sauglingen. *Beitr Orthop Traum* 21 338–342

Schindlmais er H & Kotz R (1972) Rontgenologische Beurteilung der Pfannenbodendecke des Huftgelenkes *Wien med Wschr* 122 430–432

Scholder P (1968) *L antetorsion physiologique du c l fémoral et la coxa anterorsa en marge des dysplasies congénitales de la hanche. Ther Umsch* 25 545–550

Scholder P (1967) Mésures de l antétorsion du c l femoral et evolution de la coxa antetorsa pura. *Ch r repar Traumat* 9 126–144

Schultz, P J (1924) Die Darstellung des Torsionswinkel vom Femur mit Hilfe on Rontgenstrahlen *Z orthop Chir* 44 325–334

Schwagerl W., Krepler P & Flamm Ch. (1975) Vergleichende klinische und rontgenologische *Untersuchungen zur Erfassung on Huftdysplasien* im Sauglingsalter *Z Orthop* 113 19 28

Schwarzenbach U (19 1) Die Ruckbildungstendenz der idiopatisch vermehrten Antetorsion des Schenkelhalses *Arch orthop Unfall Chir* 0 230–242

Shands A R & Steele M K (1958) *Torsion of the femur A follow up report on the use of the Dunlap method for its determination J Bone Jt Surg* 40 A 803–816

Siffert R S Ehrlich M G & Katz J F (1972) *Management of congenital dislocation of the hip Clin Orthop* 86 28–33

Siffert R S Ehrlich M G & Katz J F (1969) *Management of congenital dislocation of the hip Clin Orthop* 68 28 33

Skrzypczak J (1971) Radiologiczna ocena ksztaltu górnego końca kości udowej we wrodzonym biodrze szpotawym *Chir Nar ad Ru hu* 36 497 500

Sommer J (1971) Atypical hip click in the new born. *Acta orthop scand* 42 353–356

Sommerville, E W (1974) The nature of the congenitally dislocated hip *Proc roy Soc Med* 67 1169–1174

Steindler A (1973) Kinesiology of the human body p 281–296 *Springer* Verlag Berlin

Stohr A (1972) Beschreibung eines die Progno e der Luxationshufte beeinflussenden biologischen Faktors *Beitr Orthop Traum* 19 331–339

Sudmann E (1976) Personal communication

Sun Do Hong (1969) *The results of conservative* treatment of congenital dislocation of the hip Statistical analysis of roentgenograms *J Jap Orthop Ass* 43 1–13

Teinturier P & Dechembre, H (1968) Étude de l antéversion de la hanche de l enfant *Rev Chir orthop* 54, 545–551

Torp K H (1961) *Hofteleddsdysplasi i Troms Nord Med* 65 686–687

Tonnis D (1969) Die Grenze des Pathologischen *bei der Rontgenfruhdiagnostik der Huftdysplasie Orth Prax* 5 126–130

Tonnis D & Brunken D (1968) Eine Abgrenzung normaler und pathologischer Huftpfannendachwinkel zur Diagno e der Huftdysplasie *Arch orthop Unfall Chir* 64 197–228

Tonnis D & Trede B (1970) Untersuchungen uber den Einfluss des Spreitzhoschens auf den Huftpannendachswinkel bei angeborener Huftdysplasie. *Z Orthop* 107 263–276

Uher M (1972) Skusenosti s vyšetřovanim kych na novorozeneckém oddělení *Acta Chir orthop Traum Čech* 39 161–163

Uibe P (1959) Einfluss der Jahrzeiten auf die Haufigkeit der Luxationshuften. *Zbl Chir* 84 237–240

Walter T & Moe B (1954) *Dysplasia coxae congenita. T norske Lægeforen* 74 643–645

Watanabe R S (1974) Embryology of the human hip *Cl n Orthop* 98 8 26

Weissman S L & Salama R (1966) Treatment of congenital dislocation of the hip *in the newborn infant J Bone Jt Surg* 48-A 1319–1327

Weissman S L & Salama, R. (1969) Treatment *of congenital dislocation of the hip in the* newborn infant. *J Bone Jt Surg* 51 A 601–603

Wiberg G (1939) Studies on dysplastic acetabula and congenital subluxation *of the hip* joint *Acta chir scand* Suppl 58

Wilkinson J A (1972) A postnatal survey for congenital displacement *of the hip J Bone Jt Surg* 54 40–49

Wilkinson J A (1963) Prime factors in the etiology of c ngenital dislocation of the hip *J Bone Jt Surg* 45-B 268–283

& Williamson M (1972) Congenital dislocation of the hip Prognostic signs and methods of treatment with results *Clin Orthop* 86 21–27

James U & Sevastikoglou J A (1970) Analysis of a material of congenital dislocation of the hip *Acta orthop scand* Suppl 130 30–35

Jančova H & Gabrielová Z (1972) Pokus o zachycení a léčbu vrozeného vymknutí kyčlí v novorozeneckém období *Acta Chir orthop Traum Čech* 39 67–71

Kalenov V E (1970) Roentgenographic evaluation of the hip joint in the newborn and infants of the first months of life *Ortop Travm Protez* 31 40–45

Keller G (1975) Zum Aspekt der Hüftdysplasie in Klinik und Röntgenologie II Mitteilung Bemerkungen zur klinischen Symptomatik und zu den Mittelwerten der Pfannendachswinkel im 1 Trimenon *Z Orthop* 113 77–81

Keller G (1975) Zum heutigen Aspekt der Hüftdysplasie in Klinik und Röntgenologie III Mitteilung Röntgenologische Verlaufsbeobachtungen *Z Orthop* 113 243–259

Komprda J (1974) Diagnostika vrozené dysplazie kyčle u novorozenců *Acta Chir orthop Traum Čech* 41 448–455

Kåss A (1961) Hofteleddsdysplasi Diskusjons innlegg *Nord Med* 65 687

LaGasse, D J & Staheli L T (1972) The measurement of femoral anteversion A comparison of the fluoroscopic and biplane roentgenographic methods of measurement *Clin Orthop* 86 13–15

Lauritzen J (1971) Treatment of congenital dislocation of the hip in the newborn *Acta orthop scand* 42 259–267

LeDamany P (1908) Die angeborene Hüftgelenksverrenkung *Z orthop Chir* 21 129–169

Manlot G Lallemand D & Sauvegrain J (1964) Mésure directe de l antéversion du col femoral chez l enfant *J Radiol Electrol* 45 832–839

Marx V O (1938) New observations in congenital dislocation of the hip in the newborn *J Bone Jt Surg* 20 1095

Mears D C (1974) Treatment of the congenital dislocation of the hip *Lancet* ii 780

Medbø I U (1961) Early diagnosis and treatment of hip joint dysplasia *Acta orthop scand* 31 282–315

Medbø I U (1965) Follow up study of hip joint dysplasia treated from the newborn stage *Acta orthop scand* 35 338–347

Mitchell G P (1972) Problems in the early diagnosis and management of congenital dislocation of the hip *J Bone Jt Surg* 54 4–12

Moore F H (1974) Screening for congenital dislocation of the hip J Irish med Ass 67 104–107

Muller M E (1970) Die Hüftnahen Femurosteotomien 2nd ed Georg Thiemes Verlag Stuttgart

Nagura S (1955) Zur Ätiologie der angeborenen Hüftverrenkung *Zbl Chir* 80 1933–1943

NJÅ A (1962) Dysplasia coxae—Luxatio coxae congenita Et 5 årsmateriale *Tidsk norske Lægeforen* 82 125–129

Ortolani M (1937) Un segno poco noto e sua importanza per la diagnosi precose di prelussazione congenita *Pediatria (Napoli)* 45 129–136

Palmén K (1953) Congenital hoftledsluxation *Svenska Läk Tidn* 50 1433–1444

Palmén K (1957) Dysplasia coxae congenita *Svenska Läk Tidn* 54 1706–1720

Palmén K (1961) Preluxation of the hip joint *Acta paediat scand* Suppl 129

Palmén K (1970) Preluxation of the hip in the newborn The diagnostic work in Sweden during the years 1953–1966 *Acta orthop scand* Suppl 130

Palmén K (1976) Personal communication

Palmén K & von Rosen S (1975) Late diagnosis dislocation of the hip in children *Acta orthop scand* 46 90–101

Pap K (1956) Einfluss der Jahreszeiten auf die Haufigkeit der angeborenen Hüftverrenkung *Zbl Chir* 81 2388–2398

Papadopulos J S (1971) Die Wirkung der Spreizbehandlung auf den Schenkelschaftwinkel (CCD Winkel) kindlicher Hüftgelenke *Z Orthop* 109 39–47

Pesel Z & Ambler M (1970) Dlouhodobé skušenosti s léčením vrozené kyčelní luxace bezprostředně po narození *Acta chir orthop Traum Čech* 39 215–219

Ramstad K (1964) Dysplasia coxae congenita *Tidskr norske Lægeforen* 84 1680–1683

Ralis Z & McKibbin B (1973) Changes in shape of the human hip during its development and their relation to its stability *J Bone Jt Surg* 55 B 780–785

Record R G & Edwards J H (1958) Environmental influences related to the aetiology of congenital dislocation of the hip *Brit J prev soc Med* 12 8–22

Rippstein J (1955) Zur Bestimmung der Antetorsion des Schenkelhalses mittels zweier Röntgenaufnahmen *Z Orthop* 86 345–360

Ritter M A (1973) Congenital dislocation of the hip in the newborn *Amer J Dis Child* 125 30–32

Roebuck E J (1966) A radiological method to determine the angle of femoral neck anteversion in children *Guy s Hosp Rep* 115 119–127

Rogers S P (1931) A method for determining the angle of torsion of the neck of the femur *J Bone Jt Surg* 13 821–824

Wynne Davies R (1970) Acetabular dysplasia and familial joint laxity two etiological factors in congenital dislocation of the hip A review of 589 patients and their families *J Bone Jt Surg* 52 B 704–716

Zsernaviczky J & Türk G (1974) Über *ein* neues Röntgenzeichen in der Frühdiagnostik der kongenitalen Hüftdysplasie *Z Orthop* 112 460–465

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From the Department of Orthopaedic Surgery II (Head Professor B Stener) and the Department of Diagnostic Radiology II (Head Professor L Bjork) the Sahlgren Hospital University of Goteborg Sweden

FRACTURES OF THE ACETABULUM

A clinical radiological and experimental study

by
OLLE LANSINGER

Munksgaard
Copenhagen 1977

This study includes the following parts

PART ONE

A clinical study
by
Olle Lansinger

A radiological study
by
Olle Lansinger and Lars Irstam

PART TWO

An experimental study
by
Olle Lansinger and Bertil Romanus

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CONTENTS

PART ONE

A CLINICAL AND RADIOLOGICAL STUDY

by

Olle Lansinger and Lars Irstam

Chapter 1

INTRODUCTION

Acetabular *fractures have since* long attracted interest In 1575 Ambroise Paré stated that there is this danger in the dislocation of the hip that either the bone cannot be put into place again at least unless with much trouble or else being put in that it will presently fall out again According to Nicoll (1966) *this statement referred to fractures of the acetabulum* which could either obstruct reduction or render it unstable

Acetabular fractures with *central* dislocation of the femoral head were described by Calissen in 1778 (Schroeder 1909) In later years central acetabular fractures have been described with increasing frequency (Westerborn 1954 Stewart & Milford 1954 Rowe & Lowell 1961 Judet Judet & Letournel 1964 Lehtonen 1968)

Posterior acetabular fractures were described in the 19th Century by Cooper (1824) and Malgaigne (1855) During the first 50 years of the 20th Century few reports were published on posterior acetabular fractures In the middle of 1950 a careful study was carried out by Waller (1955) who examined 106 such fractures of a total of 2334 pelvic fractures during the period 1945 1954 He found that during this 10-year period there was an increase from 2 per cent to 8 per cent which he ascribed to increasing traffic accidents

As regards the *classification* of *central* acetabular fractures no general agreement seems to have been reached so far Stewart & Milford (1954) Eichenholtz & Stark (1964) and Pearson & Hargadon (1962) based their different classifications of central acetabular fractures on the degree of central protrusion of the femoral head Knight & Smith (1958) Rowe & Lowell (1961) and Judet Judet & Letournel (1964) found it more important to take account of the distribution of the fracture lines

Posterior acetabular fractures are as a rule classified depending on the degree of dislocation of the acetabular fragment the comminution of the fracture and the stability of the joint (Thompson & Epstein 1951 Epstein 1961 1974 Stewart & Milford 1954 Waller 1955)

As for *treatment* of acetabular fractures opinions differ

Central fracture-dislocations offer some problems in that the surgical technique is difficult Conservative measures have therefore been recommended (Bohler 1966 Stewart et al 1975) There are few comparative studies of different treatments something which further adds to the problem of evaluation

Posterior acetabular fractures without posterior dislocation of the femoral head and without posterior displacement of the acetabular fragment are treated either with traction or early mobilization without weight-bearing (Waller 1955)

Chapter 1

INTRODUCTION

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Posterior acetabular fractures in combination with posterior dislocation of the femoral head (*posterior fracture dislocations) are as a rule treated by closed reduction of the femoral head* followed by open fixation of the acetabular fragment (Waller 1955 Epstein 1974 Ender 1976), but the conservative approach with traction is also used (Bohler 1954, Brav 1962, Nerubay et al 1973)

The object of the present investigation has been

1 To carry out a clinical study based on 124 acetabular fractures in 123 patients treated during 1963 1973 at the Departments of Orthopaedic Surgery I and II Sahlgren Hospital Goteborg Special consideration has been taken to frequency, classification radiographic appearance cause of injury associated injuries and treatment

2 To perform a clinical follow up study of 101 hips in 100 patients during April 1974 January 1975

3 To carry out a radiologic study with special reference to possible development of post injury osteoarthrosis and avascular necrosis of the femoral head

Chapter 2

BASIC MATERIAL
A STUDY OF 123 PATIENTS AND A REVIEW OF LITERATURE

Material

The material consists of 123 patients with 124 fractures admitted during 1963 1973 to the *Departments of Orthopaedic Surgery I and II Sahlgren Hospital Goteborg*

Age and sex

Age and sex are presented in Figure 1 The men represent 68 per cent (82 patients) and the women 32 per cent (41 patients) The youngest patient was a 14-year-old girl and the oldest an 86-year-old lady The mean age for the men was 47 years and for the women 51 The mean age for the total material was 49 years The distribution of age with the peak incidence be tween 40-60 years corresponds well with the reports in the literature (Waller 1955 Trojan & Perschl 1956 Wechselberger 1956)

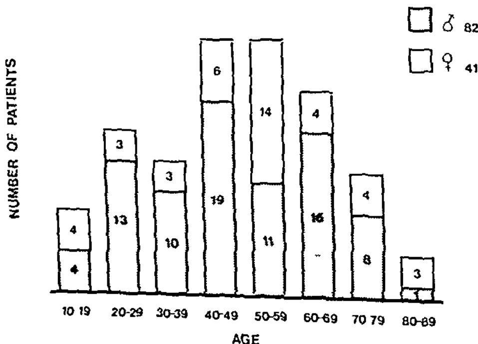


Fig 1 Age and sex distribution in 123 patients with acetabular fractures.

Side of injury

Of the 124 fractures 61 were on the right side and 63 on the left

Frequency

In 1928 Westerbom reported on 293 pelvic fractures Among these he found 51 (47 central and 4 posterior) acetabular fractures i e 17 4 per cent

In 1943 Wilenius described 88 (82 central and 6 posterior) acetabular fractures in 428 pelvic fractures collected between 1922 1939, i e 20 6 per cent

An increase from 2 to 8 per cent in posterior acetabular fractures over a 10 year period was noted by Waller (1955) in 2334 pelvic fractures

Wechselberger (1956) reported on 159 acetabular fractures in 754 pelvic fractures i e 21 per cent

In a material of 407 pelvic fractures Huittinen & Slatis (1972) found 103 acetabular fractures, i e 25 3 per cent

Solheim & Skrede (1973) found central and posterior acetabular fractures in 11 per cent of all pelvic fractures which represented 0 4 per cent of all fractures studied

Present investigation

During 1963 1973 648 patients with pelvic fractures were treated at the Sahlgren Hospital Goteborg Among these 123 had acetabular fractures i e 19 per cent which corresponds well with the frequencies reported in the literature

Classification of acetabular fractures

Anatomy of the acetabulum

The acetabulum forms the central meeting point of the os ischium the os ilium and the os pubis It forms a deep circular socket for the articulating femoral head Rowe & Lowell (1961) have divided the acetabulum into a superior posterior and inner part The superior third of the acetabulum the superior dome is the main weight bearing area of the joint and the posterior third has a stabilizing effect The inner part of the acetabulum is much more thin walled than the remaining acetabulum and increases the stability of the joint

Judet Judet & Letournel (1964) stated We consider the acetabulum to be located in the concavity of an arch formed by two columns of bone one anterior and the other posterior These columns converge and meet in a thick and compact zone of bone which is always spared by fractures of the acetabulum This zone is situated below and in front of the iliac articular surface of the sacroiliac joint The posterior or ilioischial column which is voluminous and thick descends caudad as far as the ischial tuberosity This column is composed of the vertical portion of the ischium and of that portion of the ilium immediately above the ischium On the anterolateral surface of the column lies the posterior part of the articular surface of the acetabulum the posterior acetabular rim On the medial surface of this column is the quadri

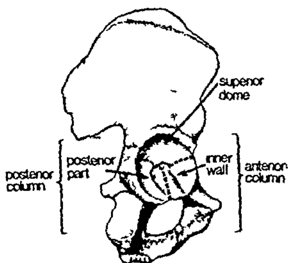




Fig 2 A External aspect of right acetabulum. *Fig B Internal aspect of right acetabulum.*

lateral surface The anterior or iliopubic column runs obliquely downward inward and anteriorly making an angle of about 60 degrees with the posterior column The anterior column consists of a short segment of the ilium and of the pubis and extends up as far as the anterior inferior iliac spine On the posterolateral surface of this column lies the anterior part of the articular surface of the acetabulum the anterior acetabular rim These two columns form an arch in which the superior angle or key stone is formed by a rounded plate of compact iliac bone the roof of the acetabulum (Figs 2 A and 2 B)

Central acetabular fractures

There are many suggestions on the classification of central acetabular fractures Some authors make their classification according to the degree of central dislocation of the femoral head (Stewart & Milford 1954 Eichenholtz & Stark 1964) Others find it more important to take account of the distribution of fracture lines and which part of the acetabulum that becomes involved (Knight & Smith 1958 Rowe & Lowell 1961 Judet Judet & Letournel 1964)

Stewart & Milford (1954) have suggested the following classification

Grade I Linear and stellate fractures through the floor of the acetabulum No dislocation of the femoral head

Grade II Comminuted fractures with a mild to moderate central displacement of the femoral head and of the acetabular fragments

Grade III Marked displacement of the fragments and protrusion of the head of the femur into the pelvis with or without comminution of the superior portion of the acetabulum

Side of injury

Of the 124 fractures 61 were on the right side and 63 on the left

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Judet Judet & Letournel (1964) made a classification according to the involvement of the iliopubic bone as a *fracture* of the anterior column and to the involvement of the "ilio ischial bone as a fracture of the posterior column Their classification is therefore

Isolated fractures of the columns (Fig 3)

Pure transverse fractures (Fig. 4)

Combined fractures of both columns (Fig 5)

Mixed fractures (Fig 6)

Present investigation

In the present investigation the central dislocation of the femoral head and the appearance of the superior dome have been estimated and a classification similar to that of Stewart & Milford (1954) has been used

The position of the femoral head was classified as follows

no dislocation

mild to moderate dislocation < 15 millimeters of the centre of the femoral head in a central direction

severe dislocation central dislocation ≥ 15 millimeters

Mode of measurement

On AP views the lower borders of the sacro-iliac joints were combined by a horizontal line drawn across the pelvis The center for each femoral head was determined and from each center a perpendicular was drawn to intersect with the horizontal pelvic line The distance from the point where the perpendicular through the centre of the femoral head *met the horizontal*

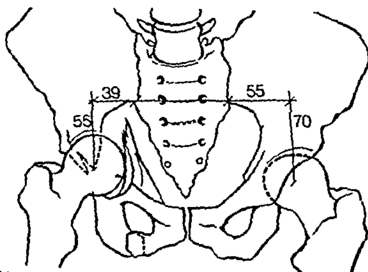


Fig 7 Schematic illustration of measurement of the central dislocation of the femoral head in a patient with a severe central dislocation of the femoral head where the fracture involves the superior dome



Fig 3 Right acetabulum with an isolated fracture of the posterior column

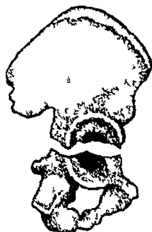


Fig 4 Right acetabulum with a transverse fracture

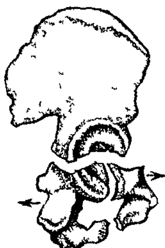


Fig 5 Right acetabulum with a T fracture

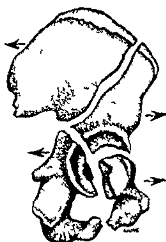


Fig 6 Right acetabulum with a mixed fracture involving the iliac wing besides the two columns

Grade IV Central dislocation with an associated fracture of the head or neck of the femur

Rowe & Lowell (1961) have classified their acetabular fractures into four groups (Group I III and IV are central fractures)

Group I Linear undisplaced fractures with either single or stellate lines

Group II Posterior fractures with a small rim fracture or a large displaced posterior sector

Group III Innerwall fractures with minor moderate and severe intrapelvic displacement of the femoral head

Group IV Superior and bursting fractures with varying degree of disruption of the acetabular socket

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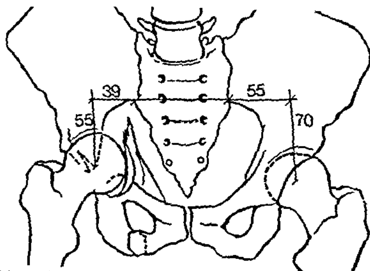


Fig 7 Schematic illustration of measurement of the central dislocation of the femoral head in a patient with a severe central dislocation of the femoral head where the fracture involves the superior dome

pelvic line was then measured on each side to the lower border of the sacro iliac joint (Fig 7) The difference in distance decided the degree of medial dislocation The same comparison of distance was made along the perpendicular to obtain information of the degree of superior dislocation

Classification of own material

I Central fractures without central dislocation of the femoral head (Fig 8)
  A – Without displacement of the acetabular fragments
  B – With displacement of the acetabular fragments

II Central fractures with mild to moderate central dislocation of the femoral head (Fig 9)
  A – The superior dome intact
  B – The superior dome fractured

III Central fractures with severe central dislocation of the femoral head (Fig 10)
  A – The superior dome intact
  B – The superior dome fractured

Central fractures in 85 patients are presented in Table 1 Age and sex distribution for patients with central acetabular fractures is presented in Figure 11



Fig 8 Radiograph of a central acetabular fracture without central dislocation of the femoral head in the right hip in a 37 year-old male



Fig 9 Radiograph of a central acetabular fracture with mild to moderate central dislocation of the femoral head where the superior dome is intact in the right hip in a 64-year-old male



Fig 10 Radiograph of a central acetabular fracture with severe central dislocation of the femoral head where the superior dome is fractured in the right hip in a 59-year-old female

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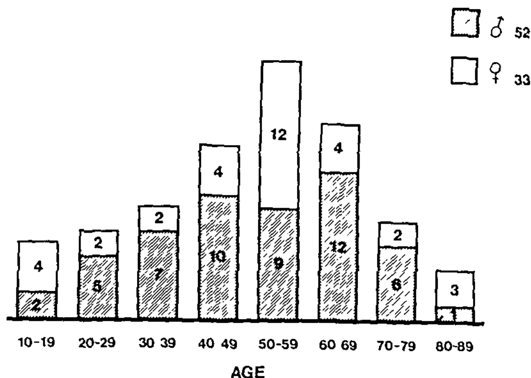


Fig 11 Age and sex distribution in 85 patients with central acetabular fractures

Table 1 *Classification of central acetabular fractures 85 patients*

Type of fracture	Number of patients
Central fracture without central dislocation of the femoral head	
Without displacement of the acetabular fragments	19
With displacement of the acetabular fragments	26
Central fracture with mild to moderate central dislocation of the femoral head	
The superior dome intact	11
The superior dome fractured	8
Central fracture with severe central dislocation of the femoral head	
The superior dome intact	5
The superior dome fractured	16
Total	85

Posterior acetabular fractures

Thompson & Epstein (1951) suggested the following classification for posterior fracture dislocations of the hip

Type I — Posterior dislocation of the femoral head without fracture or with no more than minor fracture of the posterior rim

Type II — Posterior dislocation of the femoral head with a large single fracture of the posterior rim

Type III — Posterior dislocation of the femoral head with a comminute fracture of the posterior rim

Type IV — Posterior dislocation of the femoral head with a fracture of both the rim and the floor of the acetabulum

Type V — Posterior dislocation of the femoral head with fracture of the femoral head with or without other fractures

Stewart & Milford (1954) used a similar classification dividing their posterior fractures into four grades which corresponded to Type I II III and V in the classification made by Thompson & Epstein

Waller (1955) divided his posterior fractures into three types

Type I — Fracture of the posterior superior part with no or only moderate displacement of the fragment (Fig 12)

Type II — Fracture with a single fragment of the posterior part with extensive displacement and usually dislocation of the femoral head (Fig 13)

Type III — Comminute fractures (Fig 14)

Some authors have not found it necessary to subdivide posterior acetabular fractures into various types like e g Rowe & Lowell (1961) and Judet Judet & Letournel (1964)

Present investigation

For this investigation the classification of Waller (1955) has been used In Table 2 a presentation of the types of posterior fractures in 39 patients is given Four patients were classified as Type I 15 as Type II and 20 as Type III

Table 2 *Posterior acetabular fractures in 39 patients classified according to Waller (1955)*

Type of fracture	Number of patients
Type I	4
Type II	15
Type III	0
Total	39



Fig 12 Radiograph of a posterior acetabular fracture Type I in a 44 year-old male



Fig 13 Radiograph of a posterior acetabular fracture Type II in a 24 year-old male



Fig 14 Radiograph of a posterior acetabular fracture Type III in a 23 year-old male

Of 39 posterior fractures 32 were combined with a posterior dislocation of the femoral head Thus there was no femoral head dislocation in 7 and of these 4 were classified as Type I and 3 as Type III

Age and sex distribution for patients with posterior fractures is presented in Figure 15

Comment In 7 patients there were fractures of combined posterior and central types These were classified according to the fracture which appeared radiographically dominating Five of these were central fractures which in addition had a minor fracture of the posterior acetabular rim without displacement Two were posterior fracture-dislocations which in addition had central fractures one without displacement of the acetabular fragments and one with a comminute central fracture with displacement of the acetabular fragments

The radiographic appearance of the hip joint in the diagnosis of acetabular fractures

In 1955 Waller pointed out that a reliable radiologic view of the acetabulum could not be obtained only by AP (anteroposterior) and lateral projections "The anterior and posterior acetabular margins are sometimes completely or partly superimposed and the head of the femur obscures the view Since routine radiologic examinations mainly are confined to these projections posterior acetabular fractures might be overlooked "

In 1948 Urist described a series of 15 cases of posterior acetabular fractures of which 4 were not observed at the primary radiologic examination

In 1955 Waller found 12 neglected cases in a material of 106 posterior acetabular fractures

In 1968 d Aubigne stated "among the last 100 cases of old dislocation of the hip 47 were probably unrecognized in the hospital where they were admitted in emergency

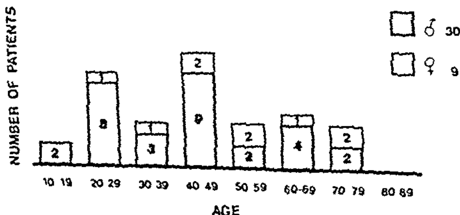


Fig 15 Age and sex distribution in 39 patients with posterior acetabular fractures



Fig 12 Radiograph of a posterior acetabular fracture Type I in a 44 year-old male



Fig 13 Radiograph of a posterior acetabular fracture Type II in a 24 year-old male



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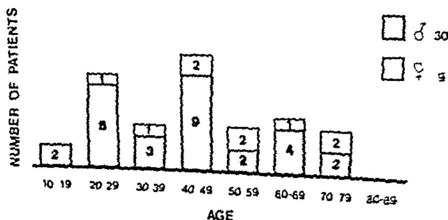


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Fig 16 B Anteroposterior view of right hip with a posterior acetabular fracture



Fig 16 C The same patient examined with a posterior oblique view according to Waller il lustrating the size of the fragment and d gree of displacement

Anteroposterior view

The normal AP radiograph of the hip shows a number of characteristics which are necessary to recognize (Fig 17)

1 *The superior channel a roentgenographic line corresponding to the arcuate line which* begins at the superior edge of the greater sciatic notch and extends downward to the pubic tubercle (a break in this line indicates fracture of the iliopubic column)

2 The ilio ischial roentgenographic line formed by the posterior four fifths of the quadri lateral surface of the pelvic bone (see Fig 2 B)

3 The roentgenographic U composed laterally of the most inferior and anterior portion of the acetabular fossa and medially of the anterior flat part of the quadrilateral surface (normally the U and the ilio ischial line intersect or are tangential)

4 The roof of the acetabulum which is prolonged in a lateral to medial direction to end on the lateral branch of the U

5 The edge of the anterior lip of the acetabulum.

6 The edge of the posterior lip of the acetabulum

Waller in 1955 stressed the importance of oblique projections in posterior acetabular fractures He suggested the following procedure the patient is placed semiprone on the examination table with the injured hip down and the healthy side up (Fig 16 A) The patient supports himself on one hand and on the flexed healthy leg so that he lies in approximately 45 degrees semiprone position Supported by a few sandbags placed under the chest and thighs, the patient does not exert pressure on the injured hip The x ray tube is directed from behind at an angle of 10 degrees cranially and is centered on the gluteal fold In this position the beams run tangentially to the upper acetabular rim which is depicted on the radiograph as a sharply arched line which continues medially to form the posterior boundary of the incisura acetabuli The postero superior part of the acetabulum is depicted unobscured by other skeletal parts (Figs 16 B and 16 C)

In central fracture dislocation of the hip the AP view demonstrates disruption of the acetabulum However it may be difficult in this view to determine accurately the extent of displacement and the exact location of the fractured fragments

Judet Judet & Letournel (1964) suggest the following projections in the radiologic diagnosis of acetabular fractures

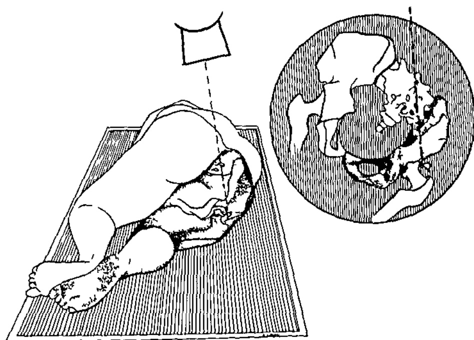


Fig 16 A Patient in semiprone position for radiographic demonstration of fracture of the posterior rim of right acetabulum according to Waller



Fig 16 B Anteroposterior view of right hip with a posterior acetabular fracture



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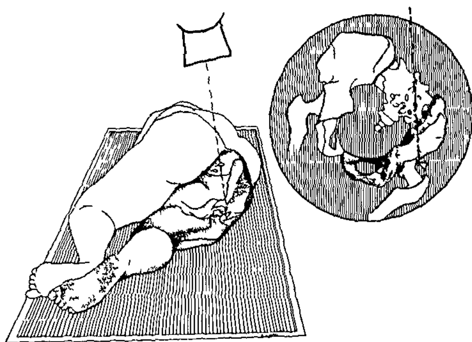


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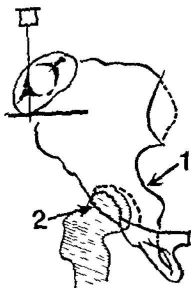




Fig 18 External oblique view of right normal hip in schematic illustration and in radiograph (Patient in supine position and rotated 45° to the right) 1) Posterior edge of the ilium 2) Anterior lip of the acetabulum.

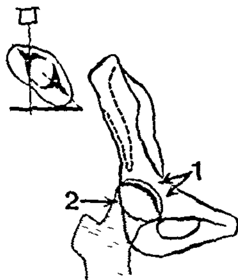
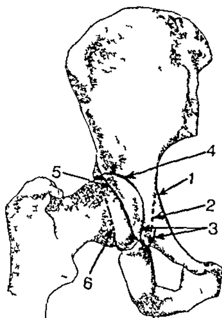




Fig 19 Internal oblique view of right normal hip in schematic illustration and in radiograph (Patient in supine position and rotated 45° to the left.) 1) Iliopubic column 2) Posterior lip of the acetabulum.



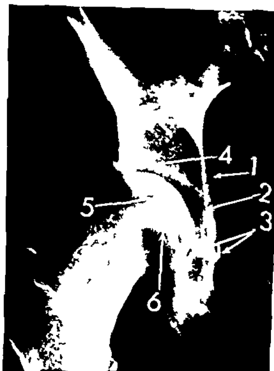


Fig 17 Schematic illustration and radiographic AP view of right hip showing 1) superior channel the arcuate line 2) ilio-ischial roentgenographic line 3) roentgenographic U 4) roof of the acetabulum 5) anterior lip of the acetabulum and 6) posterior lip of the acetabulum (From Judet Judet & Letournel J Bone Jt Surg 1964 vol 46–A p 1616 Fig 2)

External oblique view

The three-quarter external oblique view – the alar projection – (Fig 18) spreads out the iliac wing and the quadrilateral surface allowing the study of the posterior edge of the iliac bone and the anterior lip of the acetabulum

Internal oblique view

The three-quarter internal oblique view – *the obturator foramen projection* – (Fig 19) shows the entire iliopubic column in profile whereas the wing of the ilium is perpendicular to the film and viewed on edge This projection also enables one to follow the posterior lip of the acetabulum prolonged by the curve of the posterior horn of the acetabular articular surface

Present investigation

The cause of injury is presented in Table 3 Road accidents were responsible in 61 per cent (75 of 123 patients) The remaining were due to falls from heights and on the same level excepting one who was involved in a rail road accident and one in a tram accident A relation of the frequency of fractures to the frequency of traffic accidents involving personal injury was made and is presented in Table 4

Table 3 *Cause of injury in 123 patients with 124 acetabular fractures*

Cause	Central fractures	Posterior fractures	Total
Automobile accident driver or passenger	15	29	44
Motorcycle accident	0	1	1
Bicycle accident	1	0	1
Rail road accident	0	1	1
Tram accident*	1	1	2
Pedestrian hit by car	29	0	29
Fall from height	21	2	23
Fall on the same level	18	5	23
Total	85	39	124

* *One patient who sustained a central fracture of the left hip and a posterior of the right*

Table 4 *Number of injured in road accidents and number of patients with acetabular fractures in Goteborg 1963 1973*

Year	Number of injured	Patients with acetabular fractures	
		No	Per milk
1963	1558	7	4,5
1964	*1660*	10	6,0
1965	1460	9	6,2
1966	1144	9	7,9
1967	1149	9	7,9
1968	1384	5	3,6
1969	1378	4	2,9
1970	1398	3	2,2
1971	1482	7	4,7
1972	1341	9	6,7
1973	1356	3	2,2

Present investigation

The 85 patients with central acetabular fractures were all radiologically examined at the time of injury with AP views In addition 3 patients were examined with oblique views according to the technique described by Judet, Judet & Letournel

The 39 patients with posterior acetabular fractures were at the time of injury examined with AP views and in most of them a lateral projection was also made In addition 7 were examined with oblique projections and 3 with tomography

Comment Only 3 of the 85 patients with central acetabular fractures were examined with oblique projections Fourty five patients had central fractures without central dislocation of the femoral head and the treatment was for these patients strictly conservative Further radiologic examination might for this reason have been regarded as superfluous Fourty patients had a central dislocation of the femoral head In these cases the AP view demonstrated the disruption of the acetabulum but it was sometimes difficult to determine accurately the extent of displacement and the exact location of the fractured fragments However, even in these cases the therapeutic approach was conservative (35 of 40)

The 39 patients with posterior acetabular fractures were examined at the time of injury with AP projections and in most of them a lateral projection was also made The lateral projection is important in the straight posterior dislocation of the femoral head which sometimes can be difficult to detect on an AP view The straight lateral projection gives a good view of the acetabulum as this projection is close to the en face view of the acetabulum Seven patients were in addition examined with oblique projections and in 3 cases with tomography The technique described by Waller (1955) was used and this examination was performed in 5 cases after closed reduction of the dislocated femoral head in order to get a more exact view of the size and position of the posterior acetabular fragment

Cause of injury

On perusing the literature it becomes apparent that acetabular fractures of both central and posterior types mostly occur as a sequence to traffic accidents

Waller 1955 found that 69 per cent of 106 so called dash board fractures were due to traffic accidents Lehtonen (1968) reported on traffic accidents as the cause of acetabular fractures during two periods He found that between 1933 and 1953 traffic accidents were the cause in 45 per cent and between 1954 and 1962 there was an increase to 70 per cent Gothlin & Hindmarsh (1970) reported on 120 central fractures and found road accidents to be the cause in 66 per cent Nerubay et al (1973) presented a material of 107 patients of whom 81 per cent were victims in road accidents Stewart et al (1975) found the cause to be traffic accidents in no less than 85 per cent of 220 cases of both fractures and dislocations Vecsei (1975) studied the cause of injury between 1967 and 1973 and reported on 30 fractures all of which were obtained in traffic accidents

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The cause of injury is presented in Table 3 Road accidents were responsible in 61 per cent (75 of 123 patients) The remaining were due to falls from heights and on the same level excepting one who was involved in a rail road accident and one in a tram accident A relation of the frequency of fractures to the frequency of traffic accidents involving personal injury was made and is presented in Table 4

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Comment In the present *investigation the* major cause of acetabular fractures was traffic accidents Central fractures appeared mostly when the victim was hit directly by a moving object In 15 of the 75 road accidents the central fracture was obtained with the patient still in the car Sufficiently detailed information is difficult to obtain in each individual case as the sequence of events happens so fast that the patient cannot give an account of all particulars concerning the infliction of violence and position of the extremities It may well be that all 15 patients had a direct blow to the trochanteric region A blow against the knee and a sub sequent posterior fracture occurred in no less than 29 of 39 fractures This latter development corresponds well with the experience of e g Waller (1955)

Associated injuries

As a rule the trauma which causes an acetabular fracture is so violent in nature that other injuries arise simultaneously Thus both soft and other skeletal tissues can become involved Any variety of associated injury may occur and Trojan & Perschl (1956) have listed no less than 46 different lesions accompanying acetabular fractures In 79 acetabular fractures there was an associated injury in 55 7 per cent and in 10 patients the severity was such that death followed Wechselberger (1956) reported on 57 acetabular fractures which were associated with other injuries in no less than 33 instances (58 per cent) Six patients died Nerubay et al (1973) reported a frequency of 41 per cent with associated skeletal injuries and 36 per cent with associated visceral injuries in 111 acetabular fractures

Present investigation

For this investigation a distinction has been made between visceral and skeletal associated injuries They are presented in Tables 5 and 6

Comment It must be remembered that one patient representing one acetabular fracture could have more than one associated injury

It is thus evident from the tables that visceral injury was found in combination with ace tabular fracture in 13 per cent and other skeletal injury in 49 per cent No difference was noted in incidence between central and posterior fractures as regards skeletal injuries For associated visceral injury this accompanied central fractures in 12 per cent and posterior frac tures in 15 per cent

As additional information it must be mentioned that Tables 5 and 6 do not comprise the following associated injuries which did not fall under the headings of the tables There were 5 patients with posterior fracture of whom one had a dislocation of the humeroscapular joint one an anterior dislocation of the contralateral hip without fracture one a dislocation of the patella on the same side one a rupture of the anterior cruciate ligament on the ipsilateral knee and one a dislocation of the elbow

Table 5 Associated visceral injuries in 16 [illegible] patients (10 in the central and 6 in the posterior group)

Type of injury	Central fractures No. of patients	Posterior fractures No. of patients	Total
Cerebral concussion	7	4	11
Pneumothorax	0		
Rupture of the diaphragm	1	0	1
Rupture of the urinary bladder	3	0	3
Rupture of the aorta	1	0	1
Pulmonary contusion		1	3

Table 6 Associated skeletal injuries in 60 [illegible] patients (38 in the central and [illegible] in the posterior group)

Site of fracture	Central fractures No. of patients	Posterior fractures No. of patients	Total
Face	3	10	13
Upper extremity	17	8	[illegible]5
Chest	8	9	17
Spinal column	5	0	5
Femoral head	0		2
Femoral neck, medial and lateral	5	1	6
Great trochanter	[illegible]	0	
Femoral shaft	[illegible]	1	3
Patella	0	4	4
Other site in lower extremity	13	3	16

Clinical appearance

Central acetabular fractures

Often patients with acetabular fractures have other injuries which may distract the examiner who therefore can overlook the possibility of a hip condition. The patient will, however, complain of pain around the trochanteric region and in the groin. In extensive central fractures with a large hemorrhage there may be complaints of abdominal pain and the lower abdomen is tender on palpation and a slight *défense musculaire might be palpable*. However, testing the *motion of the hip joint will always yield pain which should arise suspicion of a fracture* and a radiologic examination should be carried out.

Comment In the present investigation the major cause of acetabular fractures was traffic accidents Central fractures appeared mostly when the victim was hit directly by a moving object In 15 of the 75 road accidents the central fracture was obtained with the patient still in the car Sufficiently detailed information is difficult to obtain in each individual case as the sequence of events happens so fast that the patient cannot give an account of all particulars concerning the infliction of violence and position of the extremities It may well be that all 15 patients had a direct blow to the trochanteric region A blow against the knee and a subsequent posterior fracture occurred in no less than 29 of 39 fractures This latter development corresponds well with the experience of e g Waller (1955)

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Great trochanter	2	0	2
Femoral shaft	2	1	3
Patella	0	4	4
Other site in lower extremity	13	3	16

Clinical appearance

Central acetabular fractures

Often patients with acetabular fractures have other injuries which may distract the examiner who therefore can overlook the possibility of a hip condition The patient will however complain of pain around the trochanteric region and in the groin In extensive central fractures with a large hemorrhage there may be complaints of abdominal pain and the lower abdomen is tender on palpation and a slight défense musculaire might be palpable However testing the motion of the hip joint will always yield pain which should arise suspicion of a fracture and a radiologic examination should be carried out

Posterior acetabular fractures

Posterior acetabular fractures can be difficult to detect especially in the absence of posterior dislocation of the femoral head The trauma producing the acetabular fracture is often so great that the patient may sustain other injuries which distract attention from the hip region Injuries of the acetabulum may therefore be overlooked initially (Waller 1955, d Aubigné 1968)

In cases of posterior fracture-dislocation the typical position of the leg – adduction inward rotation and shortening – usually betrays the character of the injury The knee joint is often flexed and the big toe often rests upon the tarsus of the other foot The femoral head may be felt in its posterior position Passive and active movement of the injured hip is painful and ab duction in particular is restricted

In fractures with no dislocation of the femoral head and no or only slight dislocation of the acetabular fragment the clinical picture is less clear The leg of the injured side assumes no characteristic position and the femoral head cannot be felt

In cases with patellar fractures sustained in the sitting position of an automobile driver or passenger, special caution is required as a hip lesion may be present but overlooked

'The essential safeguard against this error are firstly to insist always on a full clinical survey of the whole body in cases of major injury and secondly to make sure that the radiographs in every case of fractured femoral shaft take in the whole length of the bone and include the hip joint (Adams 1972)

Symptoms from the sciatic nerve occur in a varying degree in posterior acetabular fractures and figures from 6 to 35 per cent have been reported Stewart & Milford (1954) and Stewart et al (1975) reported 13 and 19 per cent nerve injuries respectively Waller (1955) in a ma terial of 106 posterior acetabular fractures reported 22 6 per cent and Rowe & Lowell (1961) observed as many as 35 per cent Brav (1962) reported 6 7 per cent Epstein (1974) registered 13 per cent sciatic lesions in his material of posterior fracture-dislocations of the hip

All authors who have described nerve injuries stress the importance of searching for the symptoms as early as possible

Sciatic nerve injuries

Injury to the sciatic nerve is a common complication in association with fracture-dislocation of the hip (Stewart & Milford 1954 Waller 1955 Stewart et al 1975) As mentioned above the frequencies of sciatic nerve palsy generally lie between 6 and 35 per cent

The risk of damage to the sciatic nerve is great in posterior fracture-dislocations due to the exposed position of the nerve where it leaves the infrapiriform foramen to continue down wards close to the posterior acetabular rim Fractures of the acetabular rim with displacement of the fragments carry a great risk of injury to the nerve either as simple stretching or as lac eration of the nerve by displaced fragments (Waller 1955)

Present investigation

Sciatic nerve involvement with peroneal paresis was registered in 8 patients Seven had a

posterior fracture-dislocation and one a central acetabular fracture without central dislocation of the femoral head At follow-up the paresis remained in 5 patients

Case reports

1 6?-year-old man with a central acetabular fracture without dislocation of the femoral head but with a slightly medially dislocated fragment of the acetabulum. He was treated with the extremity of the injured side on a sledge After 1 week a peroneal paresis was detected Thus remained at the time of follow up 2 years following the injury

2 58-year-old woman with a posterior fracture-dislocation Type III She was operated immediately because of the peroneal paresis. At the operation a large posterior fragment was observed being dislocated cranially and posteriorly The sciatic nerve was squeezed and hematomatous The nerve was placed back in its original position after the fracture had been fixed with two screws. At follow-up 11 years after the injury there was still a partial peroneal paresis.

3 ?4 year-old man with a posterior fracture-dislocation Type II A large posterior fragment was dislocated posteriorly Because of the patient s bad general condition operation was not done until 4 weeks had elapsed At operation a sharp fragment directed against the sciatic nerve was detected The sciatic nerve was freed and put aside and the acetabular fragment was fixed with a cancellous screw Eleven years following the injury a partial peroneal paresis remained

4 42 year-old man with a posterior fracture-dislocation Type III The patient was admitted to another hospital and the posterior fracture-dislocation was overlooked After 2 months the dislocation was observed There was a total peroneal paresis which still remained 11 years following the injury

5 50-year-old woman with a posterior fracture-dislocation Type III Acute reduction with good replacement of the fragments. Treated by traction for 6 weeks At follow-up 2 years later there was still a partial peroneal paresis.

6 21 year-old man with a posterior fracture-dislocation Type II Because of the patient s bad general condition the dislocation was not reduced until after 8 days when the patient was operated still unconscious. The sciatic nerve was freed and the acetabular fragment put into place and fixed with two pins. At the follow-up after 4 years the paresis was gone

7 22-year-old man with a posterior fracture-dislocation. Type III Acute reduction of the femoral head was performed and the acetabular fragments fell into place. The first 5 days a partial peroneal paresis was noticed After 2 weeks the paresis was gone

8 33-year-old man with a posterior fracture-dislocation Type III Operation was performed after 3 days and the fragments were put into place and fixed with two pins. During the operation the sciatic nerve was identified as normal. He was treated with traction for 6 weeks, and after 2 weeks a partial peroneal paresis was noticed At the follow-up after 3 years the patient had no symptoms of peroneal paresis.

Comments. The division of the sciatic nerve into its two main branches the tibial and peroneal nerves is demonstrable already at the origin of the nerve trunc from the lumbosacral plexus The nerve fibers of the tibial and peroneal nerves run quite separately but perineural fibrous tissue binds the two branches together so that they present as a single nerve to the naked eye The peroneal portion of the sciatic nerve always lies laterally i.e close to the posterior acetabular rim Thus this branch is more exposed to injury by e g. displaced fracture fragments from the posterior acetabular rim. These anatomical circumstances explain the clinical observation that peroneal paresis is a fairly common complication in these fractures (Walker 1955)

Treatment of acetabular fractures

Treatment of central acetabular fractures A review of literature

Central acetabular fractures without central dislocation of the femoral head or the acetabular fragments are generally treated by conservative methods Some recommend bed rest only (Rowe & Lowell 1961, Judet, Judet & Letournel 1964, Solheim & Skrede 1973) and others a short period of traction (Wechselberger 1956 Pearson & Hargadon 1962, Eichenholtz & Stark 1964)

However there is a diversity of opinion on the treatment of central acetabular fractures with central dislocation of the femoral head There are many who advocate a rather strict conservative line of treatment (Eichenholtz & Stark 1964, Nicoll 1966 Bohler 1966 Tipton et al 1975 Jahna 1976) and many who advocate surgical treatment (Armstrong 1948, Westerborn 1954 Judet Judet & Letournel 1964, Letournel 1966 Paleari & Gualtieri 1971) Further on some surgeons point out that most central dislocations should and can best be treated by conservative methods and recommend open reduction and osteosynthesis only in fractures engaging the superior dome where closed treatment has failed in reducing both the femoral head and the acetabular roof accurately (Rowe & Lowell 1961 Gothlin & Hindmarsh 1970 Carnsale et al 1975)

There is however a general consensus of opinion that the ultimate aim should be as perfect a restoration of the acetabular femoral head relationship as possible Maintenance of the congruity between the acetabular surfaces and the head of the femur is regarded as the important goal in the treatment of these fractures (Gothlin & Hindmarsh 1970 Carnsale et al 1975 Tipton et al 1975)

However this goal is sometimes difficult to achieve and incongruity between the articular surfaces becomes accepted as this in many cases do not seem to result in impaired function (Rowe & Lowell 1961 Austin 1971 Tipton et al 1975)

Conservative treatment

Many writers regard bed rest as an adequate therapy in the case of acetabular fracture without displacement (Rowe & Lowell 1961 Judet Judet & Letournel 1964) In the treatment of central fracture dislocations traction has for many decades been used as the principle means of achieving reduction and preserving the correct position In the application of traction a variety of techniques have been employed Traction has been applied either as skin traction (Pearson & Hargadon 1962) or via a pin through the femoral condyles or through the tibial tuberosity or pins through the proximal femur with the traction in a lateral direction (Lipscomb 1961) Double traction has frequently been used i e longitudinal and lateral traction in conjunction (Gelehr e 1969 Renné & Schmelzeisen 1975 Tipton et al 1975)

Some authors have emphasized the importance of reduction performed under general anesthesia in severe cases (Tipton et al 1975)

As regards the duration of traction opinions differ Periods up to 12 weeks have been reported (Carnesale et al 1975 Tipton et al 1975)

Urist (1947 1948) reported on 16 patients with central fracture-dislocations Irrespective of the position of the femoral head there was a good *response to conservative treatment with traction* and at follow up 1 3 years later the results were interpreted as excellent However in bursting fractures where reduction was impossible conservative treatment resulted in great disability He therefore suggested either fusion or arthroplasty *for this latter group*

In 1954 Stewart & Milford reviewed 193 patients with fracture-dislocation of the hip Twenty-eight of these had central fractures and 23 were treated conservatively Seven years later a follow up comprised 18 of the *conservatively treated patients and 9 of these exhibited* excellent or good results whereas the results in the remaining 9 were fair or poor

Stewart et al (1975) reported on 23 conservatively treated patients and found that the results in 11 were excellent or good and in 12 *fair or poor They stated the innerwall fractures* and explosive dome fractures of the acetabulum that are not suitable for open reduction (and very few are) can best be treated by skeletal traction"

In 1961 *Rowe & Lowell described a series of 93 patients with fractures of the acetabulum* with and without dislocation of the femoral head There were 76 central fractures and of *these 64 were treated conservatively* The average time of follow up was 6 years and the results *were excellent or good in 80 per cent (51 of 64) fair in 12 per cent (8 of 64) and poor in 8* per cent (5 of 64) In linear undisplaced fractures there were 100 per cent excellent or good results in the innerwall fractures 90 per cent excellent or good results and in the superior *dome fractures 37 per cent excellent or good results and 63 per cent fair or poor results These* authors stated that the important factor was the reduction of the femoral head to its normal position under the dome They found surgical reduction of the displaced central wall of the *acetabulum unnecessary and the only indication for operation of central fractures* was bursting or severely displaced fractures engaging the superior dome

In 1962 Pearson & Hargadon reviewed 60 patients with fractures and fracture-dislocations *of the central part of the acetabulum The results in 50 patients all of whom were treated con*servatively were reported with an account of three clinical types of fractures Type I and II were central fractures without central dislocation of the femoral head and Type III was cen*tral fractures with a central protrusion of the femoral head Mean time for follow up* was 2 5 years The overall results in their three groups were good and the patients had minor complaints *They found* good or excellent results in more than 60 per cent In the two groups in which there was no central protrusion *of the femoral head the results* were good or excellent in more than 90 per cent These authors found these fractures to be adequately treated with simple measures such as rest and a short period of skin traction The results in patients with a central protrusion of the femoral head were worse *than in those without central protrusion* However 15 patients of 23 with central dislocation of the femoral head had no or only slight pain (65 per cent) They found better results in patients (12) in whom closed reduction was not attempted

In 1964 Eichenholtz & Stark made a review of 35 patients with central acetabular fractures *They divided their fractures* into three types based on the degree of penetration of the femoral head into the pelvis Twenty-eight patients were treated conservatively and 21 of these were followed up Sixteen (75 per cent) achieved satisfactory results Six patients were operated

Treatment of acetabular fractures

Treatment of central acetabular fractures A review of literature

Central acetabular fractures without central dislocation of the femoral head or the acetabul fragments are generally treated by conservative methods Some recommend bed rest only (Rowe & Lowell 1961 Judet Judet & Letournel 1964 Solheim & Skrede 1973) and others a short period of traction (Wechselberger 1956 Pearson & Hargadon 1962 Eichenholtz & Stark 1964)

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upon and in 5 the results were satisfactory These authors believe that traction is valuable in early treatment of displaced fractures even if there is no intrapelvic protrusion of the femoral head, in order to minimize pain and diminish deformity According to their experience a stabilization will occur after 2 4 weeks so that no further traction is necessary and very little displacement will take place However they stress that weight bearing must be avoided for at least 4 months They pointed out the ability of the hip joint to produce a new acetabulum in patients with displaced fractures An autogenous intrapelvic mold arthroplasty was produced Thus they recommended closed treatment for central acetabular fractures

In 1975 Tipton et al reviewed 24 patients with central fracture dislocation of the hip All patients were treated conservatively with traction through the tibial tuberosity or combined traction They used the same classification as Rowe & Lowell (1961) and their material comprised 15 patients with innerwall fractures and 8 of these had excellent or good results Nine patients had superior dome or bursting fractures and 6 of these achieved good results However of the 15 patients with innerwall fractures 5 of 7 treated with combined traction had good or excellent results and of the patients with superior dome fractures 5 of 6 treated with combined traction had good results These authors recommend conservative treatment for central fracture dislocations with combined traction for 12 weeks

Further authors with experience of conservative treatment claim satisfactory results in 70 90 per cent (Gothlin & Hindmarsh 1970 Austin 1971 Solheim & Skrede 1973 Nerubay et al 1973)

In Table 7 a summary is given of the results of conservative treatment of central acetabular fractures as reported in the literature

Surgical treatment

The possibilities of surgical treatment were discussed as early as in the beginning of this century (Tillmans 1905 ref Lehtonen 1968) As the surgical technique is regarded as cumbersome and difficult operative treatment was for long time resorted to only in occasional cases The first open reduction was performed by Vaughn in 1912 and Levin in 1943 was the first to use internal fixation in the treatment of central acetabular fractures (Barnes & Stewart 1976) During the last 15 years thorough studies by French investigators have been published Operations for acetabular fractures were undertaken after careful consideration on the basis of pathoanatomical findings and were performed using screws and other devices for fixation (Judet Judet & Letournel 1964 Judet & Letournel 1974)

In 1948 Armstrong described 101 patients with fracture-dislocation of the hip Fifty patients were followed up and 7 of these had central acetabular fractures All 7 patients were treated conservatively and they all developed osteoarthrosis Based on this he suggested that in cases of central fractures an arthrodesis should be primarily performed

In 1928 Westerborn reported 500 cases of pelvic fractures The acetabular floor was fractured in 64 and in 21 the femoral head was dislocated centrally to a varying degree In 1954 the author reviewed 51 of the 64 patients Only 26 (51 per cent) recovered to the working capacity they had had previous to injury and 25 (49 per cent) were more or less disabled He recommended cup arthroplasty in central fracture-dislocation

Table 7 *Reported results of conse vative and surgi al tr atment of central acetabular f actures*

Auth r	No of pat followed up	Results of conservative treatment				Results of surgi al treatment			
		Excel lent	Good	Fair	Poor	Excel lent	Goo d	Fair	Poor
Stewart & Milford 1954	22	2	7	1	8	0	1	1	2
Wechselberger 1956	37	18		10	9	11		0	1
Rowe & Lowell 1961	76	51		8	5				
Zeumer 1966	25	7	9	5	4	4		5	4
Nerul ay et al 1973	53	31		6	3	–	4	1	2
Solheim & Skrede 1973	52	–	35	6	4	120	31	15	14
Judet & Letourn l 1974	180					–	23	15	10
I cke et al 1975	48					0	1	4	
Stewart et al 1975	78	11		12					
Tipt n et al 1975	24	3	11	7	3	7	16	3	3
Tr jan 1975	29					5	7	?	2
Vecsei 1975	16								
	590	185		91		230		84	

upon and in 5 the results were satisfactory These authors believe that traction is valuable in early treatment of displaced fractures even if there is no intrapelvic protrusion of the femoral head, in order to minimize pain and diminish deformity According to their experience a stabilization will occur after 2 4 weeks so that no further traction is necessary and very little displacement will take place However, they stress that weight bearing must be avoided for at least 4 months They pointed out the ability of the hip joint to produce a new acetabulum in patients with displaced fractures An autogenous intrapelvic mold arthroplasty was produced Thus, they recommended closed treatment for central acetabular fractures

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Further authors with experience of conservative treatment claim satisfactory results in 70 90 per cent (Gothlin & Hindmarsh 1970, Austin 1971 Solheim & Skrede 1973 Nerubay et al 1973)

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Table 7 *Reported results of conservative and surgical treatment of central acetabular fractures*

Author	No of pat followed up	Results of conservative treatment				Results of surgical treatment			
		Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor
Stewart & Milford 1954	22	2	7	1	8	0	1	1	2
Wechselberger 1956	37	18		10	9				
Rowe & Lowell 1961	76	51		8	5	11		0	1
Zeumer 1966	25	7	9	5	4				
Nerubay et al 1973	53	31		6	3	4		5	4
Sollheim & Skrede 1973	52	–	35	6	4	–	4	1	2
Judet & Letournel 1974	180					120	31	15	14
Ecke et al 1975	48					–	23	15	10
Stewart et al 1975	28	11		17		0	1	4	
Tipton et al 1975	24	3	11	7	3				
Trojan 1975	29					7	16	3	3
Vessel 1975	16					5	7	?	?
	590	185		91		230		84	

Judet, Judet & Letournel (1964) recommended that all acetabular fractures with displacement should be treated with open reduction and osteosynthesis of the acetabular fragments They carefully described the classification and surgical approach for these fractures In 1974 Judet & Letournel reported on 244 patients with acetabular fractures all treated surgically Sixty four of these had posterior fractures and 180 central fractures (fractures of the iliopubic column, fractures of the ilioischial column transverse fractures and mixed fractures) Results were excellent in 67 per cent, good in 17 per cent, fair in 8 per cent and poor in 8 per cent

Vecsei in 1975 reviewed 30 patients with fracture-dislocation of the hip which were operated upon in Vienna between 1965 and 1973 Twenty six of these were given an adequate follow up He used a classification like Judet, Judet & Letournel (1964) Sixteen of these fractures were central fracture dislocations and he found excellent results in 5 good in 7 fair in 2, and poor in 2

Johansson & Olerud (1971) reported on 16 operated patients and their preliminary impression of the results were satisfactory Experience of the same kind has been reported by Elliott (1956) Paleari & Gualtieri (1971) and Batra (1976)

In Table 7 a summary is given of the results of surgical treatment of central acetabular fractures as reported in the literature

Present investigation

The material of central acetabular fractures for the present investigation consisted of 85 patients with 85 fractures Of these 5 were treated *surgically* Of 80 patients treated *conservatively* there was no central dislocation of the femoral head in 45 Thirty five patients had a central dislocation of the femoral head of varying degree Sixteen of these had the superior dome intact and 19 had not

Table 8 gives the type of fracture and their treatment and Table 9 the time for immobilization and hospital stay

Details of treatment

Central fractures without dislocation of the femoral head (45 patients)

A – Without displacement of the acetabular fragments (19 patients)
All patients were immobilized in bed Only one was put into traction for one week Time of immobilization was 2 3 weeks No information could be obtained when weight bearing was instituted

B – With displacement of the acetabular fragments (26 patients)
All patients were immobilized in bed two only were put into traction Traction through the tibial tuberosity was maintained in one patient for 2 weeks and in the other for 4 weeks The mean time of immobilization was 3 weeks and following this a non weight bearing period for 2 3 weeks was prescribed

Table 8 *Type and treatment of 85 central acetabular fractures*

Type of fracture	No of patients	
	Treated conservatively	Treated surgically
Central fracture without central dislocation of the femoral head		
Without displacement of the acetabular fragments	19	
With displacement of the acetabular fragments	26	
Central fracture with mild to moderate central dislocation of the femoral head		
The superior dome intact	11	
The superior dome fractured	8	
Central fracture with severe central dislocation of the femoral head		
The superior dome intact	5	
The superior dome fractured	11	5
Total	80	5

Table 9 *Mean times of immobilization and hospital stay for patients with central acetabular fractures treated conservatively and surgically*

Type of fracture	Treated conservatively		Treated surgically	
	Immobilization (weeks)	Hospital stay (weeks)	Immobilization (weeks)	Hospital stay (weeks)
Central fractures without central dislocation of the femoral head	2–3	3 4		
Central fractures with mild to moderate central dislocation of the femoral head	4–5	6–7		
Central fractures with severe central dislocation of the femoral head	6 7	9–10	6 7	16

Central acetabular fractures with mild to moderate central dislocation of the femoral head (19 patients)

A – Superior dome intact (11 patients)
Seven patients were immobilized in bed without traction Four were treated by traction through the tibial tuberosity Time of immobilization was 4 5 weeks followed by a 4 week period of non weight bearing

B – Superior dome fractured (8 patients)
Two patients were immobilized in bed without traction Six were treated by traction applied through the tibial tuberosity Time of immobilization and non weight bearing was the same as under A

Of those 10 patients who were treated by traction through the tibial tuberosity a good reduction of the femoral head was obtained in 8 In 4 of these the superior dome was intact and in the remaining 4 the superior dome was fractured

With good reduction of the femoral head is meant that the femoral head has been reduced to its normal position Any further differentiation into acceptable poor and no reduction has not been made Those cases in which the femoral head has not been reduced to its normal position will in the following be called less satisfactory reduction

Central fractures with severe central dislocation of the femoral head treated conservatively (16 patients)

A – Superior dome intact (5 patients)
Three patients were immobilized in bed without traction Two were treated with traction (One with closed reduction under anesthesia followed by traction through the proximal femur one with a combined traction through the tibial tuberosity and proximal femur) Time of immobilization was 6 7 weeks The time for non weight bearing has not been obtained

B – Superior dome fractured (11 patients)
Four patients were immobilized in bed without traction Seven were treated by traction which was supplied through the tibial tuberosity in 2 In addition 5 had a traction applied to the proximal femur Moreover one patient was treated with closed reduction under general anesthesia (This patient was for 3 weeks put into traction through the tibial tuberosity but this gave no reduction of the femoral head After 3 weeks a closed reduction under anesthesia was performed and a lateral traction through the proximal femur was applied) Time of immobilization was 6 7 weeks The period of non weight bearing has not been obtained

Of those 16 patients with central fractures with severe central dislocation of the femoral head 9 were treated with traction In 6 of these (4 with superior dome involvement) a good reduction was obtained of the centrally dislocated femoral head In 3 reduction was less satisfactory

In 2 cases traction through the tibial tuberosity was applied which did not yield a satisfac tory reduction of the femoral head In 5 cases the traction through the tibial tuberosity was combined with lateral traction through the proximal femur and in 4 of these a good reduction of the femoral head was obtained In 2 cases a manual reduction in general anesthesia was carried out it was combined with traction through the tibial tuberosity and proximal femur in one of them and through the proximal femur only in the other In both cases a good reduc tion was obtained

Central acetabular fractures with severe central dislocation of the femoral head treated surgi cally (5 patients)

Five patients were treated with open reduction and osteosynthesis Four of these were post operatively put into traction which was applied through the tibial tuberosity Mean time of immobilization was 6-7 weeks

Case reports

1 43 year-old woman The femoral head was at the time of injury dislocated m dially-cranially 45 mm At the operation the acetabular fragment was fixed with a cerclage Reduction of the femoral head wa not achieved and postoperatively it was still dislocated 40-45 mm

2 52 year-old man The femoral head was dislocated medially-cranially 20 mm The acetabular fragment was fixed with one screw Postoperatively the femoral head remained dislocated 20 mm

3 17 year-old woman The femoral head was dislocated 20 mm medially The acetabular fragments were fixed with two plates and screws There was a good reduction of the femoral head nd po toperativ ly the femoral head was in its normal position

4 23 year-old woman The femoral head was dislocated medially-cranially 20 mm The fragm nt were fixed with three cerclages There was a good reduction of the femoral head (Fig 28)

5 36-year-old man The femoral head was dislocated medially-cranially 25 mm The acetabular fragment were fixed with a plate and four screws One did not succeed in reducing the femoral head to its normal position and postoperat ely the femoral head was dis ocated 15 mm medially

Comment The majority of cases with central dislocation of the femoral head has been treated conservatively Traction treatment has been resorted to and in most cases this has been applied through the tibial tuberosity In 7 patients lateral traction was applied to the proximal femur This is according to many (e g Lipscomb 1961 Lidstrom 1961 Nicoll 1966) the most logic way of applying traction when the femoral head is dislocated centrally as the line of traction then will be in allignment with the axis of the femoral neck Little influence seems however to be exerted on the acetabular fragments When the fractured acetabulum exhibits a persistent dislocation of the fragments despite traction open reduction appears in dicated One of the arguments advanced by those who advocate surgical intervention is that only by operative means a restoration of the acetabular fragments can be obtained and along with this an acceptable position of the femoral head

On the other hand some authors (Rowe & Lowell 1961 Eichenholtz & Stark 1964 Austin 1971) have the opinion that the realignment is unnecessary for good results They were im

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Stewart & Milford (1954) collected 193 patients with fracture-dislocations of the hip over a 30 year period Adequate follow up was made in 123 patients Of these 96 had posterior fractures These authors made a classification of posterior fracture-dislo ation into four grades where Grade I was a posterior dislocation of the femoral head with no or only a slight fracture of the posterior rim without consequence and Grade IV was a posterior dislocation of the femoral head with a fracture of the femoral neck Posterior dislocation of the femoral head with a large single fragment or a comminute fracture of the posterior acetabular rim (Grade II and III respectively) accounted for 57 patients Fourty two of these were treated conservatively Sixteen were reported with excellent or good results 26 with fair or poor results Fifteen patients were treated surgically Six had excellent or good results and 9 had fair or poor results Mean time for follow up was 7 years These authors stress the importance of early treatment and advised open procedures only when closed reduction failed when the joint was unstable after closed reduction of the femoral head and when at radiologic examination loose fragments were found in the joint

Waller (1955) gave an account of 106 patients with posterior acetabular fractures collected over a 10 year period Follow up examinations were available in 87 patients with a mean time for follow-up for 3 years and 11 months Of the 87 patients 60 were treated conservatively and 27 were operated upon Of the 60 patients treated by conservative methods 18 had fractures graded as Type I and 42 as Type II and Type III In Type I he found excellent or good results in 72 per cent in Type II in 30 per cent and in Type III in 11 per cent Twenty seven patients with fractures graded as Type II and III were operated upon In patients with Type II fractures he found excellent results in 6 patients good in 2 fair in 2 and poor in none In patients with Type III fractures he found excellent results in 5 good in 4 fair in 3 and poor in 5 Waller recommended open treatment in posterior acetabular fractures of Type II and III and he stated that Type I fractures are the only posterior acetabular fractures suited to closed treatment

Rowe & Lowell (1961) collected 93 patients with fracture-dislocation of the hip Seventeen of these had fracture of the posterior rim of the acetabulum Six of these 17 patients were treated conservatively and 11 operatively Three of the conservatively treated patients had excellent or good result 3 poor Eight of the operatively treated patients had excellent or good result 3 poor These authors recommend open treatment when there is a large displaced posterior acetabular fragment that must be reduced and fixed to restore stability of the joint or when displacement of a bone fragment is associated with sciatic nerve pressure or injury According to these authors closed treatment is satisfactory when the fragments are small and their reduction and fixation are not necessary to restore stability of the hip joint

Nerubay et al (1973) gave an account of the Tel Aviv Clinic cases between 1950 and 1969 During this period the authors collected 107 patients with 111 acetabular fractures where follow-up was available in 85 patients with 89 fractures Thirty six of these were posterior fractures and the mean time for follow up was 6 years Twenty nine of these 36 patients were treated conservatively and they found excellent or good results in 80 per cent and fair or poor in 20 per cent Only 7 patients were operated upon and the results were good in one fair in

pressed by the tendency of displaced and centrally dislocated hips treated by closed means to establish a satisfactory pseudo acetabulum after destruction and medial displacement of the inner acetabular wall

In the present investigation only 5 patients were operated upon They all had in common a severe central dislocation of the femoral head with fracture of the superior dome

Treatment of posterior acetabular fractures A review of literature

Posterior acetabular fractures were first described in 1824 by *Sir Astley Cooper (Waller* 1955) In 1855 Malgaigne described 12 cases and pointed out that a posterior acetabular frac ture should be suspected when redislocation occurred after reduction of the hip

With time some advocated conservative treatment and others surgical In cases of posterior fracture dislocation there is however today a common agreement that reduction of the dis located femoral head should be carried out as an *emergency procedure (Stewart & Milford* 1954, Waller 1955 Rowe & Lowell 1961 Lehtonen 1968 Epstein 1974 Stewart et al 1975)

Campbell (1936) collected 80 cases of posterior dislocation of the hip Of these 30 were combined with posterior acetabular fractures He divided his posterior fractures into three groups depending on the degree of posterior dislocation of the femoral head Nine could be traced and followed up all treated conservatively and all but one showed excellent results The author pointed out that all these fractures did well if they were treated with early reduc tion of the dislocation and immobilization in bed with traction for 6 weeks

Funsten et al (1938) reported on 20 patients with traumatic dislocation of the hip In 9 of these the lesion was combined with a posterior fracture of the acetabulum According to the nature of the trauma Funsten et al gave these injuries the name dash board dislocations A follow up of 8 patients was carried out after 3 years All were treated conservatively and the result was good in 4 fair in 2 and poor in 2

In a series of 101 traumatic dislocations of the hip Armstrong (1948) described 50 patients in 43 of whom the dislocation of the femoral head was combined with a fracture of the pos terior part of the acetabulum Fifteen of these were followed up after 3-4 years All but one patient were treated conservatively He found complete recovery in 63 per cent of these pa tients He stated that fractures of the posterior acetabulum with displacement of marginal fragments are usually corrected by manipulative reduction or by traction

Urist (1948) described 23 patients with fracture-dislocation of the hip Eighteen had frac ture of the posterior superior part of the acetabulum and 13 were adequately followed up Eleven of these were operated upon and 2 were treated conservatively by traction Of the pa tients treated by surgery 5 had excellent or good results 3 fair and 3 poor Both patients treated by immobilization in bed and traction had poor results He stated that minor fractures of the posterior acetabular rim could be treated by conservative methods In cases in which a significant posterior acetabular fragment remained displaced after reduction of the femoral head the final result was only fair or poor on account of degenerative changes in the hip joint He recommended that posterior rim fractures with displacement of the fragment should be treated by open reduction and internal fixation

Stewart & Milford (1954) collected 193 patients with fracture-dislocations of the hip over a 30 year period. Adequate follow up was made in 123 patients. Of these 96 had posterior fractures. These authors made a classification of posterior fracture-dislocation into four grades where Grade I was a posterior dislocation of the femoral head with no or only a slight fracture of the posterior rim without consequence and Grade IV was a posterior dislocation of the femoral head with a fracture of the femoral neck. Posterior dislocation of the femoral head with a large single fragment or a comminute fracture of the posterior acetabular rim (Grade II and III respectively) accounted for 57 patients. Fourty two of these were treated conservatively. Sixteen were reported with excellent or good results, 26 with fair or poor results. Fifteen patients were treated surgically. Six had excellent or good results and 9 had fair or poor results. Mean time for follow up was 7 years. These authors stress the importance of early treatment and advised open procedures only when closed reduction failed, when the joint was unstable after closed reduction of the femoral head and when at radiologic examination loose fragments were found in the joint.

Waller (1955) gave an account of 106 patients with posterior acetabular fractures collected over a 10 year period. Follow up examinations were available in 87 patients with a mean time for follow up for 3 years and 11 months. Of the 87 patients 60 were treated conservatively and 27 were operated upon. Of the 60 patients treated by conservative methods 18 had fractures graded as Type I and 42 as Type II and Type III. In Type I he found excellent or good results in 72 per cent, in Type II in 30 per cent and in Type III in 11 per cent. Twenty seven patients with fractures graded as Type II and III were operated upon. In patients with Type II fractures he found excellent results in 6 patients, good in 2, fair in 2 and poor in none. In patients with Type III fractures he found excellent results in 5, good in 4, fair in 3 and poor in 5. Waller recommended open treatment in posterior acetabular fractures of Type II and III and he stated that Type I fractures are the only posterior acetabular fractures suited to closed treatment.

Rowe & Lowell (1961) collected 93 patients with fracture-dislocation of the hip. Seventeen of these had fracture of the posterior rim of the acetabulum. Six of these 17 patients were treated conservatively and 11 operatively. Three of the conservatively treated patients had excellent or good result, 3 poor. Eight of the operatively treated patients had excellent or good result, 3 poor. These authors recommend open treatment when there is a large displaced posterior acetabular fragment that must be reduced and fixed to restore stability of the joint or when displacement of a bone fragment is associated with sciatic nerve pressure or injury. According to these authors closed treatment is satisfactory when the fragments are small and their reduction and fixation are not necessary to restore stability of the hip joint.

Nerubay et al. (1973) gave an account of the Tel Aviv Clinic cases between 1950 and 1969. During this period the authors collected 107 patients with 111 acetabular fractures where follow up was available in 85 patients with 89 fractures. Thirty six of these were posterior fractures and the mean time for follow up was 6 years. Twenty nine of these 36 patients were treated conservatively and they found excellent or good results in 60 per cent and fair or poor in 20 per cent. Only 7 patients were operated upon and the results were good in one, fair in

pressed by the tendency of displaced and centrally dislocated hips treated by closed means to establish a satisfactory pseudo acetabulum after destruction and medial displacement of the inner acetabular wall

In the present investigation only 5 patients were operated upon They all had in common a severe central dislocation of the femoral head with fracture of the superior dome

Treatment of posterior acetabular fractures *A review of literature*

Posterior acetabular fractures were first described in 1824 by Sir Astley Cooper (Waller 1955) In 1855 Malgaigne described 12 cases and pointed out that a posterior acetabular fracture should be suspected when redislocation occurred after reduction of the hip

With time some advocated conservative treatment and others surgical In cases of posterior fracture-dislocation there is however today a common agreement that reduction of the dislocated femoral head should be carried out as an emergency procedure (Stewart & Milford 1954, Waller 1955 Rowe & Lowell 1961 Lehtonen 1968 Epstein 1974 Stewart et al 1975)

Campbell (1936) collected 80 cases of posterior dislocation of the hip Of these 30 were combined with posterior acetabular fractures He divided his posterior fractures into three groups depending on the degree of posterior dislocation of the femoral head Nine could be traced and followed up all treated conservatively and all but one showed excellent results The author pointed out that all these fractures did well if they were treated with early reduction of the dislocation and immobilization in bed with traction for 6 weeks

Funsten et al (1938) reported on 20 patients with traumatic dislocation of the hip In 9 of these the lesion was combined with a posterior fracture of the acetabulum According to the nature of the trauma Funsten et al gave these injuries the name dash board dislocations A follow up of 8 patients was carried out after 3 years All were treated conservatively and the result was good in 4 fair in 2 and poor in 2

In a series of 101 traumatic dislocations of the hip Armstrong (1948) described 50 patients in 43 of whom the dislocation of the femoral head was combined with a fracture of the posterior part of the acetabulum Fifteen of these were followed up after 3-4 years All but one patient were treated conservatively He found complete recovery in 63 per cent of these patients He stated that fractures of the posterior acetabulum with displacement of marginal fragments are usually corrected by manipulative reduction or by traction

Urist (1948) described 23 patients with fracture-dislocation of the hip Eighteen had fracture of the posterior superior part of the acetabulum and 13 were adequately followed up Eleven of these were operated upon and 2 were treated conservatively by traction Of the patients treated by surgery 5 had excellent or good results 3 fair and 3 poor Both patients treated by immobilization in bed and traction had poor results He stated that minor fractures of the posterior acetabular rim could be treated by conservative methods In cases in which a significant posterior acetabular fragment remained displaced after reduction of the femoral head the final result was only fair or poor on account of degenerative changes in the hip joint He recommended that posterior rim fractures with displacement of the fragment should be treated by open reduction and internal fixation

Table 10 *Reported results of conservative and surgical treatment of posterior acetabular fractures*

Authors	No of pat followed up	Type of fracture	Results of conservative treatment: Excellent	Good	Fair	Poor	Results of surgical treatment: Excellent	Good	Fair	Poor
Urist 1948	13		0		0	2	5		3	3
Stewart & Milford 1954	57	II+III	16		26		6		9	
Walker 1955	87	I	3	10	5	0				
		II	1	6	10	6	6	2	2	0
		III	0	7	10	7	5	4	3	5
Rowe & Lowell 1961	17		3		3		8		3	
Bray 1962	70		42		10		14		4	
Nerubay et al 1973	36		23		5	1	0	1	2	4
Salth am & Skred 1973	14			1	0	1	–	8	0	4
Epstein 1974	203	II	0	7	7	8	0	14	6	1
		III	0	1	15	19	0	32	10	19
		IV	0	5	10	23	0	11	7	8
Judet & Letournel 1974	64						53	2	6	3
Ecke et al 1975	47						–	22	7	13
Stewart et al 1975	81	II+III	39		18		17		7	
Trojan 1975	36						12	11	10	3
	725		159		186		238		142	

2 and poor in 4 Thus these authors reported good results with conservative treatment and recommend open treatment only for fractures that could not be reduced conservatively for fractures that remained unstabled after closed reduction of the femoral head and in lesions of the sciatic nerve by compression of the femoral head or bony fragments without recovery for 1 2 weeks

Solheim & Skrede (1973) presented a material of 95 patients with fracture of the acetabulum Sixty six of these were followed up Fifty two were central acetabular fractures and 14 posterior acetabular fractures Twelve of the 14 patients with posterior fractures were operated upon with good results in 60 per cent Only 2 patients were treated conservatively one was given good result and one poor They recommended open treatment in all posterior acetabular fractures with dislocation of the acetabular fragment

Epstein (1974) gave an account of 242 posterior fracture dislocations of the hip Twohundredandthree belonged to Type II IV in the classification described on page 17 Ninety five patients were treated conservatively with closed reduction of the femoral head followed by immobilization in bed with or without traction Sixty one were treated with closed reduction of the femoral head followed by open fixation of the acetabular fragment and 47 were treated by primary open reduction of the femoral head and osteosynthesis of the acetabular fragment(s) Satisfactory results were obtained in 14 per cent in the first group 44 per cent in the second group and 63 per cent in the third group From this series he concluded that early primary open reduction with removal of all loose fragments of bone and cartilage and restoration of stability by internal fixation of the fracture of the acetabular rim offers the best prognosis in delaying the appearance of posttraumatic osteoarthrosis and to minimize its severity

On materials varying in size conservative treatment has been suggested irrespective of size and displacement of fragment and good results have been registered in 60 to 80 per cent (Brav 1962 Nicoll 1966) The mode of treatment has varied somewhat and in some cases traction is advocated in others immobilization in bed only

Surgical treatment has been suggested by Lehtonen (1968) Judet Judet & Letournel (1964) Johansson & Olerud (1971)

In Table 10 a summary of reported results of conservative and surgical treatment of posterior acetabular fractures is presented

Present investigation (Tables 11 and 12)

Conservative treatment (19 patients)

The Type I fracture was treated with immobilization in bed without traction Time for immobilization was 1 2 weeks Fifteen fractures of Type II and III were treated conservatively Of these 9 were immobilized in bed without traction the remaining 6 being treated with traction through the tibial tuberosity In 9 patients the fragment still remained dislocated after reduction of the femoral head Three of these were treated with traction and 6 were immobilized in bed without traction There was no redislocation of the femoral head in any of the patients Times for immobilization and hospital stay are presented in Table 12

Summary on diagnosis and treatment of acetabular fractures

In summary there is agreement among most surgeons who treat fractures of the acetabulum on the following

1. For a detailed analysis of acetabular fractures the radiologic examination should include several projections of the joint
2. When the femoral head is dislocated posteriorly acute reduction should be performed
3. A large posterior acetabular fragment associated with instability requires open reduction and fixation of the acetabular fragment
4. The presence of a bone fragment in the hip joint blocking the reduction of a posteriorly dislocated femoral head is an indication for open reduction
5. A sciatic nerve palsy in combination with a posteriorly dislocated acetabular fragment requires early surgical exploration

The principle point of disagreement concerns the management of central acetabular fractures with displacement of fragments and central dislocation of the femoral head

Table 11 *Type and treatment of 39 posterior acetabular fractures*

Type of fracture	No of patients	
	Treated conservatively	Treated surgically
Type I	4	
Type II	5	10
Type III	10	10
Total	19	20

Table 12 *Mean times of immobilization and hospital stay for patients with posterior acetabular fractures treated conservatively and surgically*

Type of fracture	Treated conservatively		Treated surgically	
	Immobilization (weeks)	Hospital stay (weeks)	Immobilization (weeks)	Hospital stay (weeks)
Type I	1–2	2–3	–	
Type II	3–4	4	4–5	7 8
Type III	4–5	7	5–6	8–9

Surgical treatment (20 patients)

In this material 20 patients with Type II and III fractures were operated upon The indication for operation in 15 patients was a remaining large displacement of one or several posterior fragments after reduction of the femoral head Three patients were operated upon because of impossibility to reduce the femoral head one patient because of redislocation of the femoral head after reduction and one patient because of sciatic nerve involvement with acute peroneal paresis

Sixteen patients were operated upon within 1 week one after 2 weeks one after 3 weeks and 2 after 4 weeks Various types of operative fixation were employed (Palmer s pin screw and cerclage)

Twelve of the patients operated upon were immobilized postoperatively in bed without traction 7 were put into traction and one had a plaster of Paris Times for immobilization and hospital stay are presented in Table 12

Table 13 *Type and treatment of 66 central acetabular fractures (Follow-up series)*

Type of fracture	No of patients	
	Treated conservatively	Treated surgically
Central fracture without central dislocation of the femoral head		
Without displacement of the acetabular fragments	13	
With displacement of the acetabular fragments	17	
Central fracture with mild to moderate central dislocation of the femoral head		
The superior dome intact	11	
The superior dome fractured	7	
Central fracture with severe central dislocation of the femoral head		
The superior dome intact	4	
The superior dome fractured	9	5
Total	61	5

Table 14 *Type and treatment of 35 posterior acetabular fractures (Follow-up series)*

Type of fracture	No of patients	
	Treated conservatively	Treated surgically
Type I	3	
Type II	5	10
Type III	9	8
Total	17	18

Time of follow-up

The time of follow-up varied from 1 12 years with a mean time of 6 1 years The distribution of the material according to the time of follow up was

9 – 12 years	25 patients
7 – 9 "	19 "
5 – 7 "	17 "
3 – 5 "	14
1 – 3 "	25 "

Chapter 3

A FOLLOW UP STUDY OF 100 PATIENTS

Material

A follow up of acetabular fractures treated during 1963 1973 was carried out from April 1974 to January 1975 *Of the original 123 patients with 124 fractures the follow up com* prised 100 patients representing 101 fractures Twenty of the patients had died Two were not accessible to any verbal or functional inquiry One patient could not be traced

Of the 100 followed up patients 35 were women and 65 were men

The mean age for the whole material at follow up was 45 years, for women 47 years and for the men 43 years

In Tables 13 and 14 the classification is presented of central and posterior fractures at follow up

Deceased patients

Three patients died in connection with the injury, one as an immediate consequence to the accident one after 8 days in pneumonia and one after 2 months in myocardial infarction Seventeen patients died of various causes unrelated to the injury 1 7 years after the accident

Mode of follow up

Ninety five patients were questioned and examined by myself One patient was examined by another orthopaedic surgeon Three patients refused examination and one lived abroad These 4 patients replied to a written questionnaire

Three patients who had a hip arthroplasty or hip fusion performed at a later date as a re constructive procedure were given a final clinical and radiologic rating for their hips prior to this later operation (One patient with a central fracture with severe central dislocation of the femoral head was operated upon after 3 years with a Smith Petersen cup One patient with a posterior fracture-dislocation of Type III treated surgically was operated upon with an arthrodesis 2 years after injury One patient with a posterior fracture-dislocation of Type II combined with a fracture of the femoral head had a Moore prosthesis implanted at the time of injury and after 2 years a Girdlestone procedure was performed)

[illegible] redu tion of the femoral head following

	[illegible]		[illegible] ory reduction		Superior dome fractured			
					Good reduction		Less satisfactory reduction	
	[illegible]	[illegible]ing	Pain	Walking	Pain	Walking	Pain	Walking
	–	–	–	–	–	–	–	–
	–	–	–	1	–	–	1	1
3	1	–	1	–	2	–	–	–
4	[illegible]	–	1	–	–	–	1	–
5	–	1	[illegible]	3	1	1	–	1
6	1	3	3	3	1	1	1	1
	4	4	7	7	4	4	3	3
Mean value	4 3	5 8	5 0	5 0	4 3	5 8	4 0	4 3

C ntral fra t[illegible] s with [illegible] r d[illegible] ation f the f moral h ad

Superior dome intact				Superior dome fractured			
Good reduction		Less satisfactory reduction		Good reduction		Less satisfactory reduction	
Pain	Walking	Pain	Walking	Pain	Walking	Pain	Walking
–	–	–	–	–	–	–	–
–	–	–	–	–	–	1	3
–	–	–	–	2	1	2	–
1	–	–	–	1	–	–	–
–	–	–	–	–	1	–	1
1	[illegible]	[illegible]	[illegible]	1	2	[illegible]	1
2	[illegible]	2	2	4	4	5	5
5 0	6 0	6 0	6 0	4 0	5 0	4 0	3 4

Chapter 3

A FOLLOW UP STUDY OF 100 PATIENTS

Material

A follow up of acetabular fractures treated during 1963 1973 was carried out from April 1974 to January 1975 Of the original 123 patients with 124 fractures the follow up comprised 100 patients representing 101 fractures Twenty of the patients had died Two were not accessible to any verbal or functional inquiry One patient could not be traced

Of the 100 followed up patients 35 were women and 65 were men

The mean age for the whole material at follow up was 45 years, for women 47 years and for the men 43 years

In Tables 13 and 14 the classification is presented of central and posterior fractures at follow up

Deceased patients

Three patients died in connection with the injury one as an immediate consequence to the accident one after 8 days in pneumonia and one after 2 months in myocardial infarction Seventeen patients died of various causes unrelated to the injury 1 7 years after the accident

Mode of follow up

Ninety five patients were questioned and examined by myself One patient was examined by another orthopaedic surgeon Three patients refused examination and one lived abroad These 4 patients replied to a written questionnaire

Three patients who had a hip arthroplasty or hip fusion performed at a later date as a reconstructive procedure were given a final clinical and radiologic rating for their hips prior to this later operation (One patient with a central fracture with severe central dislocation of the femoral head was operated upon after 3 years with a Smith Petersen cup One patient with a posterior fracture-dislocation of Type III treated surgically was operated upon with an arthrodesis 2 years after injury One patient with a posterior fracture-dislocation of Type II combined with a fracture of the femoral head had a Moore prosthesis implanted at the time of injury and after 2 years a Girdlestone procedure was performed)

fied by Charnley (1972) has been used (Table 15)

The results of the follow up are presented in Tables 16-28

Pain

A summarizing presentation for all fractures is made in Table 16

Central fractures (66 patients)

Thirty patients had a *central fracture without central dislocation of the femoral head* (Table 17) The results concerning pain for this type of fracture were very satisfactory Twenty six patients (87 per cent) had no or only slight or intermittent pain Mean value was 5 6 points On comparison between patients with and without displacement of the acetabular fragments it is surprising to see that patients with displacement had better results than those without displacement of the acetabular fragments

A *mild to moderate central dislocation of the femoral head* was present in 18 patients (Table 18) Nine patients had no or only slight or intermittent pain and 4 had pain only after some activity (72 per cent) Mean value was 4 5 points The superior dome was intact in 11 patients and fractured in 7 Pain was less pronounced in patients with the superior dome intact (4 7 points) than in those with the superior dome fractured (4 1 points)

Thirteen patients with a *severe central dislocation of the femoral head were treated conservatively* (Table 19) Six patients had no pain and 2 pain only after some activity (61 per cent) Mean value was 4 5 points The superior dome was intact in 4 patients and 3 of these had no pain and one had pain only after some activity (5 5 points) In 9 patients the superior dome was fractured and the mean value for these patients was 4 0 points

Five patients with a *severe central dislocation of the femoral head were treated surgically* (Table 19) In all patients the superior dome was fractured and the mean value for pain was 3 6 points

Table 17 *Results concerning pain and walking in central fractures without central dislocation of the femoral head (30 fractures in 30 patients)*

Pain Point	Without dislocation of acetabular fragment	With dislocation of acetabular fragments	Walking Point	Without dislocation of acetabular fragments	With dislocation of acetabular fragment
1	–	–	1	–	–
2	1	–	2	1	–
3	1	–	3	1	–
4	2	–	4	1	–
5		2	5	–	2
6	9	15	6	10	15
	13	17		13	17
Mean value	5 2	5 9		5 3	5 9

Results

Assessment of results

It has become apparent from the literature that the assessment of results varies considerably due to the type of evaluation used (Anderson 1972) To minimize the examiner s subjective opinion and also to make an attempt to cover as many functional activities as possible in an objective way a numerical system suggested by d Aubignée & Postel (1954), later modi

Table 15 *Assessment table*

Points	Pain	Walking	Total motion (degrees)
1	Severe spontaneous	Bedridden or few yards Two sticks or crutches	0–30
2	Severe on attempting to walk Prevents all activity	Time and distance very limited with or without sticks	31–60
3	Pain tolerable Permitting limited activity	Limited with one stick (less than 1 hour) Difficult without stick Able to stand long periods	61–100
4	Pain only after some activity disappears quickly at rest	Long distances with one stick Limited without a stick	101–160
5	Slight or intermittent pain on starting to walk but getting less with normal activity	No stick but a limp	161–210
6	No pain	Normal	211–

Table 16 *Results concerning pain (101 fractures in 100 patients)*

Pain	Points	Central fractures	Posterior fractures	Total
Severe spontaneous	1	–	–	–
Severe on attempting to walk Prevents all activity	2	3	3	6
Pain tolerable Permitting limited activity	3	11	4	15
Pain only after some activity disappears quickly at rest	4	11	7	18
Slight or intermittent pain on starting to walk but getting less with normal activity	5	5	3	8
No pain	6	36	18	54
		66	35	101
Mean value		4 9	4 8	4 9

Table 20 *Correlation between results concerning pain and walking in patients with good and less satisfactory reduction of the femoral head following conservative treatment (31 fractures in 31 patients)*

Points	Central fractures with mild to moderate dislocation of the femoral head								Central fractures with severe dislocation of the femoral head							
	Superior dome intact				Superior dome fractured				Superior dome intact				Superior dome fractured			
	Good reduction		Less satisfactory reduction		Good reduction		Less satisfactory reduction		Good reduction		Less satisfactory reduction		Good reduction		Less satisfactory reduction	
	Pain	Walking	Pain	Walking	Pain	Walking	Pain	Walking	Pain	Walking	Pain	Walking	Pain	Walking	Pain	Walking
1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	1	–	–	1	1	–	–	–	–	–	–	1	3
3	1	–	1	–	2	–	–	–	–	–	–	–	2	1	2	–
4	2	–	1	–	–	–	1	–	1	–	–	–	1	–	–	–
5	–	1	2	3	1	1	–	1	–	–	–	–	–	1	–	1
6	1	3	3	3	1	3	1	1	1	2	2	2	1	2	2	1
	4	4	7	7	4	4	3	3	2	2	2	2	4	4	5	5
Mean value	4 3	5 8	5 0	5 0	4 3	5 8	4 0	4 3	5 0	6 0	6 0	6 0	4 0	5 0	4 0	3 4

Table 18 *Results concerning pain and walking in central fractures with mild to moderate central dislocation of the femoral head (18 fractures in 18 patients)*

Pain Points	Superior dome intact	Superior dome fractured	Walking Points	Superior dome intact	Superior dome fractured
1	–	–	1	–	–
2	–	1	2	1	1
3	2	2	3	–	–
4	3	1	4	–	–
5	2	1	5	4	2
6	4	2	6	6	4
	11	7		11	7
Mean value	4 7	4 1		5 3	5 1

Table 19 *Results concerning pain and walking in central fractures with severe central dislocation of the femoral head (18 fractures in 18 patients)*

Pain points	Superior dome intact treated conservatively	Superior dome fractured		Walking points	Superior dome intact treated conservatively	Superior dome fractured	
		Treated cons	Treated surg			Treated cons	Treated surg
1	–	–	–	1	–	–	–
2	–	1	–	2	–	3	–
3	–	4	2	3	–	1	–
4	1	1	3	4	–	–	–
5	–	–	–	5	–	2	4
6	3	3	–	6	4	3	1
	4	9	5		4	9	5
Mean value	5 5	4 0	3 6		6 0	4 1	5 2

Correlation between results concerning pain in patients with good and less satisfactory reduction of the femoral head following conservative treatment (Table 20)

A mild to moderate or severe central dislocation of the femoral head was present in 31 of the 61 conservatively treated patients It was mild to moderate in 18 and severe in 13 The superior dome was intact in 15 of the 31 patients and fractured in 16

In the 15 patients with the superior dome intact a good reduction of the femoral head was achieved in 6 patients In the remaining 9 the reduction was less satisfactory The pain recorded for the reduced cases was 4 5 points and for the others 5 2 points

Walking

A summarizing presentation for all fractures is made in Table 22

Central fractures (66 patients)

Central fractures without central dislocation of the femoral head (Table 17) Twenty five of 30 patients had normal walking (80 per cent) The mean value was 5 6 points

A *mild to moderate central dislocation of the femoral head* was present in 18 patients and 10 of these had normal walking (Table 18) The mean value was 5 2 points Whether the superior dome was fractured or not did not appear to influence the walking capacity in these patients

Of the 13 patients with *severe central dislocation of the femoral head treated conservatively* 7 had a normal walking (Table 19) An interesting observation was made in the 4 patients in whom the superior dome was intact The grading was 6 in all In those 9 patients who had the superior dome fractured the result was graded as 4 1

In those 5 patients with *severe central dislocation of the femoral head treated surgically* the mean value was 5 2 points (Table 19)

Correlation between results concerning walking in patients with good and less satisfactory reduction of the femoral head following conservative treatment (Table 20)

Of 16 patients with varying degree of central dislocation of the femoral head and the superior dome fractured a good reduction could be achieved in 8 These patients had a better grading (5 4 points) than those 8 patients in whom a less satisfactory reduction was obtained (3 8 points) A good reduction in 6 of those 15 patients who had the superior dome intact did also result in better walking than for those with less satisfactory reduction (5 8 versus 5 2 points)

Table 22 *Results concerning walking (101 fractures in 100 patients)*

Walking	Points	Central fractures	Posterior fractures	Total
Bedridden or few yards Two sticks or crutches	1			—
Time and distance very limited with or without sticks	2	6	3	9
Limited with one stick (less than 1 hour) Difficult without stick Able to stand long period	3	2	3	5
Long distances with one stick Limited without a stick	4	1		3
No stick but a limp	5	14	[illegible]	16
Normal	6	43	5	68
		66	35	101
Mean value		5 3	5 [illegible]	5 3

On judging the influence of the degree of reduction on the degree of pain in the 16 patients with the superior dome fractured no difference could be found between those with a good reduction and those with a less satisfactory reduction (4 1 versus 4 0 points)

Posterior fractures (35 patients)

The intensity of pain in posterior fractures could be related to the type of fracture (Table 21)

Only 3 patients had a *Type I fracture*, and all 3 were free from pain

Type II fracture was present in 15 patients Ten patients had no or only slight or intermit tent pain and 3 had pain only after some activity The mean value was 5 2 points Those pa tients treated conservatively had better results than those treated surgically (5 4 versus 4 9 points)

Seventeen patients had a *Type III fracture* Nine patients were treated conservatively and 8 surgically The result concerning pain was 4 2 points in those treated conservatively and 4 6 in those treated surgically

In 8 patients with Type II and III fractures conservatively treated, the acetabular fragment remained dislocated after reduction of the femoral head The mean value for these patients was 4 6 points

Table 21 *Results concerning pain in posterior fractures (35 fractures in 35 patients)*

Points	Type I	Type II		Type III		Type II and III
	Treated conserva tively	Treated conserva tively	Treated surgically	Treated conserva tively	Treated surgically	Treated conserva tively with the fragment re mained dislocated
1	–		–	–	–	–
2	–	–	1	1	1	–
3	–	–	1	1	2	1
4	–	1	2	4	–	4
5	–	1	–	1	1	–
6	3	3	6	2	4	3
	3	5	10	9	8	8
Mean value	6 0	5 4	4 9	4 2	4 6	4 6

Walking

A summarizing presentation for all fractures is made in Table 22

Central fractures (66 patients)

Central fractures without central dislocation of the femoral head (Table 17) Twenty five of 30 patients had normal walking (80 per cent) The mean value was 5 6 points

A *mild to moderate central dislocation of the femoral head* was present in 18 patients and 10 of these had normal walking (Table 18) The mean value was 5 2 points Whether the superior dome was fractured or not did not appear to influence the walking capacity in these patients

Of the 13 patients with *severe central dislocation of the femoral head treated conservatively* 7 had a normal walking (Table 19) An interesting observation was made in the 4 patients in whom the superior dome was intact The grading was 6 in all In those 9 patients who had the *superior dome fractured the result was graded as 4 1*

In those 5 patients with *severe central dislocation of the femoral head treated surgically* the mean value was 5 2 points (Table 19)

Correlation between results concerning walking in patients with good and less satisfactory reduction of the fen or Il cad following corsenatite treatment (Table 20)

Of 16 patients with varying degree of central dislocation of the femoral head and the superior dome fractured a good reduction could be achieved in 8 These patients had a better grading (5 4 *points) than those 8 patients in whom a less satisfactory reduction was obtained* (3 8 points) A good reduction in 6 of those 15 patients who had the superior dome intact did also result in better walking than for those with less satisfactory reduction (5 8 versus 5 ? points)

Table [illegible] *Results concerning walking (101 fractures in 100 patients)*

Walking	Points	Central fractures	Io t nor fr ictur s	Total
Bedridden or a few yards Two sticks or crutches	1			
Ti and dista ce v ry limited with r without ticks	2	6	3	9
Li ited with ne sti k (less than 1 hour) Difficult without stick Abl t tand l ng period	3	2	3	5
L g di tan e with one sti k Li it d w thout a stick	4	1	2	3
N t k but a lim p	5	14	2	16
N r al	6	43	25	68
		66	35	101
Mean value		5 3	5 2	5 3

Posterior fractures (35 patients)

Results concerning walking in posterior fractures are given in Table 23

All 3 patients with *Type I fracture* had normal walking

Twelve of the 15 patients who had a *Type II fracture* had normal walking including all 5 patients treated conservatively

Of 17 patients with *Type III fracture* 9 were treated conservatively and 8 surgically The result in walking was 5 2 points in those treated without operation and 4 5 points in those operated upon

In 8 patients with Type II and III fractures treated conservatively the acetabular fragments remained dislocated after reduction of the femoral head Mean value for these patients was 5 6 points

Total motion

The range of total motion (flexion abduction adduction, inward and outward rotation) for each group is presented in Tables 24 and 25

Central fractures (63 patients) (Table 24)

In 23 of the 29 patients with *central fractures without central dislocation of the femoral head* a normal range of motion was registered The remaining 6 patients had decreased mobility which foremost concerned flexion and rotation

In 7 of the 16 patients with *central fractures with mild to moderate dislocation of the femoral head* there was a restriction of motion, particularly concerning flexion and rotation The remaining 9 had a normal range of motion

Table 23 *Results concerning walking in posterior fractures (35 fractures in 35 patients)*

Points	Type I	Type II		Type III		Type II and III
	Treated conservatively	Treated conservatively	Treated surgically	Treated conservatively	Treated surgically	treated conservatively with the fragment remained dislocated
1	–	–	–	–	–	–
2	–	–	1	–	2	–
3	–	–	1	1	1	–
4	–	–	1	1	–	1
5	–		–	2	1	1
6	3	5	7	5	4	6
	3	5	10	9	8	8
Mean value	6 0	6 0	5 1	5 2	4 5	5 6

Table 24 *Results concerning mobility in central fractures (63 patients)*

Total Motion	Points	Central fractures without central dislocation of the femoral head		Central fractures with mild to moderate central dislocation of the femoral head		Central fractures with severe central dislocation of the femoral head		
		Without displacement of fragments	With displacement of fragments	Superior dome intact	Superior dome fractured	Superior dome intact	Superior dome fractured	
							Treated conservatively	Treated surgically
0-30	1	–	–	–	–	–		
31-60	2	–	–	–	–	–	–	–
61 100	3	–	–	–	–	–	1	1
101 160	4	2	–	1	2	–	5	2
161 210	5	1	3	3	1	2	2	1
211	6	10	13	5	4	2	1	1
		13	16	9	7	4	9	5
Mean value		5 6	5 8	5 4	5 3	5,5	4 3	4 4

Table 25 *Results concerning mobility in posterior fractures (34 patients)*

Total Motion	Points	Type I	Type II		Type III	
			Treated conservatively	Treated surgically	Treated conservatively	Treated surgically
0-30	1	–	–	–	–	–
31-60	2	–	–	–	–	–
61 100	3	–		1	–	1
101 160	4	–		2	2	2
161 210	5	–		1	1	1
211	6	2	5	6	6	4
		2	5	10	9	8
Mean value		6 0	6 0	5,2	5 4	5,0

In 8 of the central fractures with mild to moderate dislocation a good reduction was ob tained of the femoral head and 5 of these patients had a normal range of motion Of the re maining 3 patients 2 had 5 points and one had 4 points

Among those 8 patients in whom reduction had been less satisfactory 4 had 6 points 2 had 5 points and 2 had 4 points

In the 13 patients with *central fractures with severe central dislocation of the femoral head treated conservatively* only 3 had a normal range of motion Four patients had 5 points 5 had 4 points and one had 3 points No difference in range of motion was registered between those with a good reduction (6 patients) and those with less satisfactory reduction of the fe moral head (7 patients)

One of the 5 patients with *central fractures surgically treated* had normal motion Four pa tients had a decreased range of motion (3 5 points)

Posterior fractures (34 patients) (Table 25)

Twenty three patients had a normal range of motion Three patients had 5 points, 6 had 4 points and 2 had 3 points

Summary of results in pain and walking

To facilitate the comparison of the results of this investigation with the radiologic findings and with other reported results it has been found of practical value to make a summary of the results in groups of excellent good fair and poor

The results concerning pain and walking have been summarized as follows

Excellent 12 points Good 10 11 points, Fair 8 9 points Poor 2 7 points

The results as graded above are presented in Tables 26 and 27

Seventy three per cent of the whole material had excellent or good result 12 per cent fair and 16 per cent poor

Results concerning total motion have been excluded from this summary A correlation be tween the results concerning pain and walking and total motion has been made and is pre sented in Table 28 From this it can be seen that a close relationship exists

Central fractures (66 patients)

Central fractures without central dislocation of the femoral head (30 patients) Ninety per cent had excellent or good results Twenty three patients had excellent result 4 good 1 fair and 2 poor Those 3 patients with fair or poor results had all central fractures without dis placement of the acetabular fragments

Central fractures with mild to moderate central dislocation of the femoral head (18 patients) Sixty seven per cent had excellent or good results Five patients had excellent result 7 good 4 fair and 2 poor Eleven patients had the *superior dome intact* the result was excellent in 3 good in 6 fair in 1 and poor in 1 Reduction of the femoral head has not influenced in the results in this group In 7 patients the *superior dome was fractured* the result was excellent in 2 good in 1 fair in 3 and poor in 1 In those 4 patients with fair or poor result there was

Table 26 *Results concerning pain and walking graded in excellent to poor in 66 patients with central acetabular fractures*

Result	Without central dislocation of the femoral head	With mild to moderate central dislocation of the femoral head		With severe central dislocation of the femoral head			Total
		Superior dome intact	Superior dome fractured	Superior dome intact	Superior dome fractured		
					Treated conservatively	*Treated surgically*	
Excellent	23	3	2	3	2	–	33
Good	4	6	1	1	1	1	14
Fair	1	1	3	–	2	4	11
Poor	2	1	1	–	4		8
	30	11	7	4	9	5	66

Table 27 *Results concerning pain and walking graded in excellent to poor in 35 patients with posterior acetabular fractures*

Result	Type I	Type II		Type III		Total
		Treated conservatively	Treated surgically	Treated conservatively	Treated surgically	
Excellent	3	3	6	2	4	18
Good	–	2	1	4	1	8
Fair	–		–	1	–	1
Poor	–	–	3	2	3	8
	3	5	10	9	8	35

Table 28 *Correlating results between pain and walking and total motion in 96 patients with 97 acetabular fractures*

Result pain and walking	Total motion > 211	210-161	160-101	100-61	60-31	30-0	Total
Excellent	42	5	1	–	–	–	48
Good	14	6	1	–	–	–	21
Fair	3	3	5	1	–	–	12
Poor	–	2	11	3	–	–	16
	59	16	18	4	–	–	97

a good reduction of the femoral head in 2 and a less satisfactory reduction in 2

Central fractures with severe central dislocation of the femoral head treated conservatively (13 patients) Fifty four per cent had excellent or good result Five patients had excellent result, 2 good, 2 fair and 4 poor In 4 patients the *superior dome was intact*, the result was excellent in 3 and good in 1 In 2 patients there was a good reduction of the femoral head and in 2 the reduction was less satisfactory In 9 patients the *superior dome was fractured* the result was excellent in 2 good in 1, fair in 2 and poor in 4 In 4 patients there was a good reduction of the femoral head One of these had excellent result 2 fair and 1 poor In 5 patients there was a less satisfactory reduction of the femoral head One of these had excellent result 1 good and 3 poor

Of 31 patients treated conservatively with a mild to moderate or severe central dislocation of the femoral head the *superior dome was intact* in 15 Eighty seven per cent had excellent or good result and 13 per cent fair or poor Six patients had excellent result 7 good 1 fair and 1 poor In 6 patients there was a good reduction of the femoral head Any difference in the results between patients with good and less satisfactory reduction was not obtained

In 16 patients with a mild to moderate or severe central dislocation of the femoral head treated conservatively the *superior dome was fractured* Six of these patients had excellent or good result (38 per cent) and 10 fair or poor (62 per cent) Four had excellent result 2 good 5 fair and 5 poor Good reduction of the femoral head was obtained in 8 patients Two of these had excellent result 1 good 4 fair and 1 poor

Central fractures with a severe central dislocation of the femoral head treated surgically (5 patients) One patient had good result and 4 fair

Posterior fractures (35 patients)

Type I (3 patients) All 3 patients had excellent result

Type II – treated conservatively (5 patients) Three patients had excellent result and 2 good In all the femoral head was dislocated posteriorly

Type II – treated surgically (10 patients) Six patients had excellent result 1 good 0 fair and 3 poor In all patients the femoral head was dislocated posteriorly A poor result was recorded in the following 3 patients 1 A 74 year-old woman who was treated with acute reduction of the femoral head and put into traction After 4 weeks there was a redislocation posteriorly of the femoral head Open reduction of the femoral head and fixation of the acetabular fragment was performed 2 A 60 year-old man Closed reduction of the femoral head failed and after 3 days an open procedure was performed Because of fracture of the femoral head the patient was operated with a Moore prosthesis The posterior acetabular fragment was put into place and fixed with two pins After 6 months pain progressed to a degree which eventually made a Girdlestone procedure necessary 2 years after injury 3 A 77 year-old man who was treated with acute reduction of the femoral head After 3 days the joint was opened and the posterior acetabular fragment put into place and fixed with two pins

Type III – treated conservatively (9 patients) Two patients had excellent result 4 good 1 fair and 2 poor Seven patients had at the first radiologic examination a posterior dislocation of the femoral head and in 2 patients no posterior dislocation could be observed These 2 pa

tients had excellent and good result A poor result was recorded in the following 2 patients 1 A 40-year-old man The posterior dislocation of the femoral head was not noticed until after 2 months 2 A 50 year-old woman who was treated with traction through the tibial tuberosity for 3 weeks following acute reduction of the femoral head

Type III – treated surgically (8 patients) Four patients had excellent result 1 good 0 fair and 3 poor *In all patients but one there was a posterior dislocation of the femoral head* A poor result was recorded in the following 3 patients 1 A 58-year-old woman with a comminute fracture of the acetabulum She was operated upon acute with open reduction of the dislocated femoral head and fixation of a big posterior acetabular fragment with two pins *In addition this patient had a central fracture and after the operation the femoral head was dislocated* 10 mm medially She was postoperatively treated with traction through the tibial tuberosity for 6 weeks 2 A 47 year-old woman who was treated with acute closed reduction after 6 12 hours After 1 week she was operated upon and a big posterior acetabular fragment was put into place and fixed with two pins *Postoperatively she was immobilized in bed for 7 weeks* Two years after the injury she developed necrosis of the femoral head leading to arthrodesis 3 A 20 year-old man who was treated with acute closed reduction of the femoral head Because of redislocation he was operated after 8 days with open reduction of the femoral head and osteosynthesis of the posterior acetabular fragments

Of 32 patients with posterior acetabular fractures classified as Type II and III-fractures 14 were treated conservatively and 18 surgically Of those treated conservatively 79 per cent had excellent or good results and 21 per cent fair or poor Five patients had excellent result 6 good 1 fair and 2 poor Of those patients treated surgically 67 per cent had excellent or good result and 33 per cent poor Ten patients had excellent result 2 good 0 fair and 6 poor

There were poor results in 8 patients of whom 5 had unfavourable features i.e redislocation of the femoral head delayed reduction of the femoral head never reduced dislocation of the femoral head and a central fracture in addition to the posterior

Time of onset of post-injury symptoms

Those patients who did not have 6 points for pain and walking were interrogated as to the time of onset of symptoms Eighty per cent maintained that their discomfort had developed at the accident and remained stationary ever since Eight per cent had a début after 1 2 years 2 per cent after 2-4 years and 10 per cent after 4 years

Working capacity

Central fractures (66 patients)

Central fractures without central dislocation of the femoral head (30 patients) Five patients were retired at the time of injury Four received sick compensation for other reasons Two had changed to lighter work One received sick compensation because of the hip injury One still received rehabilitation treatment (1 year follow up) Seventeen remained in their original work which for 9 was of the heavy type i e labour Two were house wifes and 6 had a lighter type of work

Central fractures with mild to moderate central dislocation of the femoral head (18 patients) Two patients were retired at the time of injury One received sick compensation due to additional injury (fracture of the tibia) Two received sick compensation because of hip discomfort Two had changed to lighter work Eleven remained in their original work, which in 5 was of the heavy type Six had a lighter type of work

Central fractures with severe central dislocation of the femoral head treated conservatively (13 patients) Three patients were retired at the time of injury One had changed to lighter work Two received sick compensation because of hip discomfort Seven returned to their original work which for one patient was of the heavy type Two were house wifes and 4 had a lighter type of work

Central fractures with severe central dislocation of the femoral head treated surgically (5 patients) One patient received sick compensation because of hip discomfort Two had changed to lighter work One was still at school (could not partake in physical exercise) One returned to original work as a heavy worker

Posterior fractures (35 patients)

Type I (3 patients) All 3 patients returned to their original work One was a heavy worker and 2 had a lighter type of work

Type II – treated conservatively (5 patients) One patient had changed to a lighter work The remaining 4 returned to their original work Of these one was a heavy worker and 3 had a lighter type of work

Type II – treated surgically (10 patients) One patient was retired at the time of injury One was still in school (had done his military service and could partake in physical exercise) One received sick compensation due to hip discomfort One had changed to lighter work Six remained in their original work which for 4 was of the heavy type Two had a lighter type of work

Type III – treated conservatively (9 patients) One patient was retired at the time of injury One received sick compensation due to hip discomfort Two had changed to lighter work Five remained in their original work Of these one was a heavy worker and 4 had a lighter type of work

Type III – treated surgically (8 patients) Two patients had sick compensation due to hip discomfort One had changed to lighter work Five remained in their original work which for 2 was of a heavy type One patient was a house wife and 2 had a lighter type of work

Chapter 4

RADIOLOGIC FOLLOW UP STUDY

Degenerative changes

Osteoarthrosis and avascular necrosis of the femoral head are late complications which are considered to yield poor results In Table 29 a summary of late complications as reported in the literature is presented

Osteoarthrosis

Of 1152 reported patients (Table 29) osteoarthrosis was found in 6 6 to 62 per cent

Avascular necrosis of the femoral head

Avascular necrosis of the femoral head developed in 4 to 30 per cent (Table 29)

As regards posterior fractures Stewart & Milford (1954) and Brav (1962) noted that this complication occurred less frequently in fractures treated by conservative methods However Waller (1955) presented a higher percentage of avascular necrosis in patients not being operated upon

Most authors stress the importance of early reduction of the post riorly dislocated femoral head in order to minimize the frequency of necrosis and arthrotic changes (Stewart & Milford 1954 1975 Brav 1962 Epstein 1974) When reduction was delayed for more than 12 hours the incidence of avascular necrosis became three times as frequent (Brav 1962)

In a material of 242 patients with posterior dislocations and fracture-dislocations Epstein (1974) noted 18 per cent avascular necrosis In those patients treated with primary open reduction of the femoral head the frequency of avascular necrosis was 5.3 per cent and in the remainder 21 per cent

Ectopic ossification

Ectopic ossification occurs to a varying extent after acetabular fractures This has particularly been the case when surgical treatment has been carried out Stewart & Milford (1954) noted 2 2 per cent in their patients treated conservatively Waller (1955) found 14 cases in 106 posterior acetabular fractures (13 1 per cent) Ten of these cases belonged to the operated category and 4 to the group treated conservatively Brav (1962) reported a frequency of 13 2 per cent and Judet & Letournel (1974) a frequency of 20 2 per cent

As a rule ectopic ossification has not been accompanied by any symptoms and no special treatment has been recommended

Central fractures with mild to moderate central dislocation of the femoral head (18 patients) Two patients were retired at the time of injury One received sick compensation due to additional injury (fracture of the tibia) Two received sick compensation because of hip discomfort Two had changed to lighter work Eleven remained in their original work which in 5 was of the heavy type Six had a lighter type of work

Central fractures with severe central dislocation of the femoral head treated conservatively (13 patients) Three patients were retired at the time of injury One had changed to lighter work Two received sick compensation because of hip discomfort Seven returned to their original work which for one patient was of the heavy type Two were house wifes and 4 had a lighter type of work

Central fractures with severe central dislocation of the femoral head treated surgically (5 patients) One patient received sick compensation because of hip discomfort Two had changed to lighter work One was still at school (could not partake in physical exercise) One returned to original work as a heavy worker

Posterior fractures (35 patients)

Type I (3 patients) All 3 patients returned to their original work One was a heavy worker and 2 had a lighter type of work

Type II – treated conservatively (5 patients) One patient had changed to a lighter work The remaining 4 returned to their original work Of these one was a heavy worker and 3 had a lighter type of work

Type II – treated surgically (10 patients) One patient was retired at the time of injury One was still in school (had done his military service and could partake in physical exercise) One received sick compensation due to hip discomfort One had changed to lighter work Six remained in their original work which for 4 was of the heavy type Two had a lighter type of work

Type III – treated conservatively (9 patients) One patient was retired at the time of injury One received sick compensation due to hip discomfort Two had changed to lighter work Five remained in their original work Of these one was a heavy worker and 4 had a lighter type of work

Type III – treated surgically (8 patients) Two patients had sick compensation due to hip discomfort One had changed to lighter work Five remained in their original work which for 2 was of a heavy type One patient was a house wife and 2 had a lighter type of work

Present investigation

At the clinical follow up a radiologic study was also performed The purpose of the radiologic examination was to determine the frequency and the degree of possible degenerative changes of the fractured joint and the frequency of ectopic ossification

Examination technique

In 83 patients both hips were examined in the supine position but no examination with weight-bearing on the hip was carried out

An AP view was taken with the thigh slightly inward rotated and with the centre of the beam directed to the femoral head Furthermore a projection according to Cleave – also called Lauenstein s projection – was made This implies an AP view of the acetabulum with the thigh abducted 45° and with an external rotation of about 60° In patients with a decreased mobility of the hip joint this projection was made in the utmost position the patient could attain In Cleave s projection the acetabulum appears mainly the same as in the AP view projection but the femoral head becomes externally rotated thus visualizing anterior and posterior parts of the femoral head

In 10 patients there were some diagnostic doubts whether degenerative lesions were present or not These patients were also examined under weight-bearing conditions i e in a standing position An AP view of each hip was taken as well as an "en fa e view An "en face" view implies a semilateral projection of the hip where the centre of the beam was directed transversally through the pelvis and centralized through a point slightly posterior to the opposite femoral head The object of that particular projection was to obtain a beam direction parallel to other parts of the joint space than those demonstrated on the AP projection The "en face" projection demonstrates parts of the anterior joint space the central joint space and parts of the posterior joint space In order to get an ideal positioning of each hip fluoroscopy was utilized

All films obtained at the follow up study were studied together with all earlier films in order to make a complete review of each case

Definitions and classifications

Osteoarthrosis

The earliest radiologically definable stage of osteoarthrosis of the hip is narrowing of the joint space The width of the joint space reflects the thickness of the articular cartilage In this study the joint space was interpreted as abnormally decreased if it was more than 1 millimeter narrower than the contralateral normal side

The presence of osteophytes without a concomitant narrowing of the joint space was accordingly excluded as a single criterion of the diagnosis of osteoarthrosis of the hip These considerations have also been suggested by Danielsson (1964) and Ahlback (1971)

Table 29 *Frequency of osteoarthrosis and necrosis of the femoral head and ectopic ossification reported in the literature in patients with fracture-dislocation of the hip*

Author	No of pat followed up	Mean time of follow up-years	Type of fracture	Osteo arthrosis per cent	Avascular Necrosis per cent	Ectopic ossification per cent
Stewart & Milford 1954	77	7 0	Posterior acetabular fractures	60	30 (17)	
			Central fractures	59	23	
Waller 1955	87	3 9	Posterior acetabular fractures	44 8 (50)	19 6 (26)	13 1☆
Wechselberger 1956	37	6	Central fractures	53	27	2 7
Rowe & Lowell 1961	93	6 0	Posterior acetabular fractures	23	23	15
			Central fractures	17	8	
Brav 1962	91	6 7	Posterior fracture-dislocation	50	25 (13,5)	13,2
Pearson & Hargadon 1962	50	2,5	Central fractures	62		
Gothlin & Hindmarsh 1970	51	6 0	Central fractures	33		
Austin 1971	25		Central fractures	44	4	
Nerubay et al 1973	89	6 0	Posterior acetabular fractures	22	13 8	
			Innerwall fractures	31 4	2 8	
			Superior dome fractures	50,2	17 0	
Solheim & Skrede 1973	66	4 4	Posterior acetabular fractures	36		
			Central fractures	25		
Epstein 1974	242	7 3	Posterior fracture-dislocation	36	18	4
Judet & Letournel 1974	244		All acetabular fractures	6 6	8 6	20,2

The figures within parenthesis represent the frequencies for patients treated conservatively

☆ 14 of 106 patients

Present investigation

At the clinical follow up a radiologic study was also performed The purpose of the radiologic examination was to determine the frequency and the degree of possible degenerative changes of the fractured joint and the frequency of ectopic ossification

Examination technique

In 83 patients both hips were examined in the supine position but no examination with weight-bearing on the hip was carried out

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In 10 patients there were some diagnostic doubts whether degenerative lesions were present or not These patients were also examined under weight-bearing conditions i.e in a standing position An AP view of each hip was taken as well as an "en face view An en face view implies a semilateral projection of the hip where the centre of the beam was directed transversally through the pelvis and centralized through a point slightly posterior to the opposite femoral head The object of that particular projection was to obtain a beam direction parallel to other parts of the joint space than those demonstrated on the AP projection The "en face projection demonstrates parts of the anterior joint space the central joint space and parts of the posterior joint space In order to get an ideal positioning of each hip fluoroscopy was utilized

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The presence of osteophytes without a concomitant narrowing of the joint space was accordingly excluded as a single criterion of the diagnosis of osteoarthrosis of the hip These considerations have also been suggested by Danielsson (1964) and Ahlback (1971)

In this study a two stage classification of osteoarthrosis was utilized

Grade 1 Mild to moderate arthrosis

Slight to moderate narrowing of the joint space None or only slight secondary changes of sclerosis and/or cyst formation in the acetabulum and/or the femoral head No slight or mod erate formation of osteophytes

Grade 2 Severe osteoarthrosis

Advanced or total obliteration of the joint space Marked secondary changes of sclerosis cyst formation and large osteophytes The obliteration was considered advanced when the joint space was found to be less than 1 millimeter

Avascular necrosis of the femoral head

The radiographic appearance of avascular necrosis is an archlike radiolucency which occurs parallell to the subchondral surface of the femoral head Its presence alone without any of the other characteristic features, was regarded good evidence of ischemic necrosis

A narrow lip of sclerotic bone surrounds the radiolucent zone At first, the joint space is normal but later when the necrotic ischemic bone collapses the articular surface is flattened and the articular cartilage destroyed (Edeiken & Hodes 1975)

Material

Ninety three patients with 94 acetabular fractures were examined radiologically Of 100 patients followed up clinically 6 could not be assessed by radiologic examination Four of these refused any clinical or radiologic examination and instead replied to a written question naire Two patients could be examined clinically but refused radiologic examination

Moreover one patient with a posterior fracture dislocation with damage to the femoral head has been excluded as the acute procedure following injury was an arthroplasty with a Moore prosthesis which after 2 years was removed and turned into a Girdlestone hip

Results

In 2 patients mild to moderate arthrotic changes were observed at the first radiologic ex amination

At the follow up arthrotic changes were found in 37 out of 94 hips (39 per cent) The dis tribution of arthrotic changes within the different types of acetabular fractures is demon strated in Table 30 The 37 patients who developed osteoarthrosis had a mean age of 46 years at the time of injury 21 were men and 16 women The mean time for follow up of the 37 patients with osteoarthrotic changes was 5 years and 5 months (The mean time for follow up of the whole material was 6 1 years)

There were 8 patients who developed necrosis of the femoral head in addition to arthrotic changes (Table 31) Five of these patients had a central fracture and 3 a posterior fracture of Type II or III in combination with a posterior dislocation of the femoral head

Table 30 *Results of radiologic follow-up (osteoarthrosis) in comparison to clinical rating*

Type of fracture	Normal joint space				Grade I arthrosis				Grade II arthrosis				Total
	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	Excellent	Good	Fair	Poor	
Central fractures without central dislocation of the femoral head													
Without displacement of the acetabular fragments	9	1	1					1				1	13
With displacement of the acetabular fragments	12	3							1				16
Central fracture with mild to moderate central dislocation of the femoral head													
Superior dome intact	2	2				3	1					1	9
Superior dome fractured	2	1	1				2					1	7
Central fractures with severe central dislocation of the femoral head													
Superior dome intact	1	1			1				1				4
Superior dome fract treated conservatively			1		1					1	1	3	7
Superior dome fract treated surgically			1			1	1				2		5
Posterior fractur													
Type I	2												2
Type II treated cons.	3	1				1							5
Type II treated surg	5				1	1		1				1	9
Type III treated con	2	1		1		1	1					1	9
Type III treated surg	1	1			3							3	8
	39	13	4	1	6	7	5	2	2	1	3	11	94
	57				20				17				

In this study a two stage classification of osteoarthrosis was utilized

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There were 8 patients who developed necrosis of the femoral head in addition to arthrotic changes (Table 31) Five of these patients had a central fracture and 3 a posterior fracture of Type II or III in combination with a posterior dislocation of the femoral head

Central fractures (61 patients)

Twenty three patients had radiologic evidence of osteoarthrosis (38 per cent) Eleven had mild to moderate arthrotic changes (Grade I) and 12 had severe arthrotic changes (Grade II) In addition 5 had necrosis of the femoral head

Central fractures without central dislocation of the femoral head (29 patients) Twenty-six patients had no signs of osteoarthrosis or avascular necrosis (90 per cent) Mild to moderate arthrotic changes were found in one patient and severe arthrotic changes in 2 These latter both had necrosis of the femoral head One of them a 68 year-old woman had sustained a minor acetabular fracture when falling on the same level After 2 1/2 years she developed necrosis of the femoral head (Fig 20) The other patient a 66-year-old man had sustained a central acetabular fracture with 10 millimeter medial dislocation of a fragment The radio logic examination at the time of injury showed mild to moderate osteoarthrosis and 9 months after injury the patient developed a severe osteoarthrosis and femoral head necrosis

At the time of injury there was a dislocation between the acetabular fragments exceeding 3 millimeter in 16 patients In all those patients the fracture gap had been filled in with bone and a congruent socket had developed (Fig 22)

Central fractures with mild to moderate central dislocation of the femoral head (16 patients) In 8 patients no signs of osteoarthrosis or femoral head necrosis could be detected (50 per cent) Six patients had mild to moderate and 2 severe arthrotic changes In one patient with severe arthrotic changes mild to moderate osteoarthrosis had been observed at the time of in jury The other patient with severe osteoarthrosis had in addition necrosis of the femoral head

In 8 patients there was a good reduction of the femoral head Five of these had no arthrotic changes nor any femoral head necrosis and 3 had mild to moderate osteoarthrosis

In 8 patients there was less satisfactory reduction of the femoral head In 3 of these there were no signs of degenerative changes Of the remaining 5 3 had mild to moderate and 2 se vere osteoarthrosis One of the latter developed necrosis of the femoral head

Central fractures with severe central dislocation of the femoral head treated conservatively (11 patients) Three patients had no signs of osteoarthrosis Two patients had mild to mod erate and 6 had severe osteoarthrosis One of the patients with mild to moderate arthrotic changes and one of the 6 patients with severe arthrotic changes had femoral head necrosis

In 6 patients there was a good reduction of the femoral head In 3 of these no signs of osteo arthrosis or femoral head necrosis could be detected One had mild to moderate and 2 had severe arthrotic changes

In 5 patients a less satisfactory reduction was obtained All of these had osteoarthrotic changes one mild to moderate and 4 severe One of the patients sustained a pertrochanteric fracture at the time of injury He developed a severe osteoarthrosis which eventually was treat ed by an arthroplasty according to Smith Petersen

Central fractures with severe central dislocation of the femoral head treated surgically (5 patients) One patient had no signs of osteoarthrosis Two patients had mild to moderate and 2 had severe arthrotic changes

Table 31 *Avascular necrosis of the femoral head in 8 patients*

Type of fracture	No of patients	Time until reduction of the femoral head	Damage to the femoral head visible on original radiograph	Changes first visible on radiograph	Clinical rating
Central fractures without central dislocation of the femoral head					
Without displacement of the acetabular fragments	1	–	–	2 years 6 months	poor
With displacement of the acetabular fragments	1	–	–	9 months	excellent
Central fractures with mild to moderate central dislocation of the femoral head					
Superior dome intact					
Superior dome fractured	1	not reduced	–	7 months	poor
Central fractures with severe central dislocation of the femoral head					
Superior dome intact	1	not reduced	lateral superior part	12 months	excellent
Superior dome fractured treated conservatively	1	1 day	–	10 months	poor
Superior dome fractured treated surgically					
Posterior fractures					
Type I					
Type II treated surgically	1	< 12 hours Redislocation after 4 weeks	anterior part	1 year 6 months	poor
Type III treated surgically	2	1 < 12 hours	–	10 years 9 months	poor
		2 < 12 hours	medial ant. part	11 months	poor

Two deceased patients with a posterior fracture Type III operated upon could be examined 4 years after injury They both developed arthrosis Grade II and necrosis of the femoral head Time for reduction was within 12 hours and no damage to the femoral head could be observed at the time of injury for either of these patients Changes were first visible on radiograph at 3 months

Type I (2 patients) Two patients with posterior fractures of this type were radiologically examined and none of them showed any sign of o teoarthrosis

Type II – treated conservatively (5 patients) Four patients had no signs of osteoarthrosis and one had mild to moderate arthrotic changes

Type II – treated surgically (9 patients) Five patients had a normal joint space without any radiologic signs of osteoarthrosis or femoral head necrosis Three patients had mild to moderate and one had severe arthrotic changes This patient also developed femoral head necrosis One patient had at the time of injury a fracture of the femoral head with a little fragment dislocated The fragment was removed and the dislocated posterior acetabular fragment was fixed with two pins This patient had at the time of follow up 11 years after the operation mild to moderate arthrosis

Type III – treated conservatively (9 patients) Six patients had no signs of osteoarthrosis 2 had mild to moderate and one had severe osteoarthrosis

Type III – treated surgically (8 patients) Two patients had no signs of osteoarthrosis 3 had mild to moderate and 3 had severe osteoarthrosis Two of the latter developed a femoral head necrosis

Fourteen patients classified as Type II and III were treated conservatively and in 4 of these degenerative changes were observed (29 per cent) Seventeen patients classified as Type II and III were treated surgically Ten of these had osteoarthrotic changes (60 per cent) of which 3 had femoral head necrosis

Thirty patients were not included in the radiologic follow-up study Only 6 of these had been radiologically examined for more than 1 year following the injury They are specified as follows

One patient with a posterior acetabular fracture Type III combined with a posterior dislocation of the femoral head treated surgically was examined up to 2 years and 6 months after injury At the time of injury no damage of the femoral head was observed After 1 month ectopic ossification was noted and after 3 months necrosis of the femoral head developed and also a total destruction of the joint cartilage

One patient with a posterior fracture Type III treated surgically was examined up to 4 years and 2 months after injury He developed necrosis of the femoral head and ankylosis of the hip joint and ectopic ossification

One patient with a central fracture with severe central dislocation of the femoral head and fracture of the superior dome was examined up to 3 years and 9 months after injury A mild to moderate osteoarthrosis could then be observed This patient had been treated conservatively without traction

The other 3 patients had all central fractures without central dislocation of the femoral head and were examined up to 4 years after injury None of them showed any sign of osteoarthrosis or femoral head necrosis

Correlation between clinical results and radiologic findings in 94 hips with acetabular fractures

In those 57 hip joints without radiologic signs of osteoarthrosis or femoral head necrosis the clinical results were excellent to good in 52 cases (91 per cent) Of the 47 patients with clinically excellent results 39 had no radiologic evidence of osteoarthrosis (83 per cent) (Table 33).

In 14 patients with mild to moderate or severe central dislocation of the femoral head treated conservatively a good reduction of the femoral head had been achieved There was no redislocation centrally of the femoral head There seems to have been little influence on the centrally dislocated fragments by traction Further it seems that in the healing procedure nature had filled in the space between the femoral head and the fragments and that a smooth congruent articulating surface had developed

In those 13 patients with mild to moderate or severe central dislocation of the femoral head treated conservatively in whom less satisfactory reduction had been achieved a new pseudo-acetabulum" or ' false joint' between the two joint components was observed (Fig 25)

Correlation between osteoarthrotic changes and reduction of the femoral head

A correlation between arthrotic changes and reduction of the femoral head in 27 patients with mild to moderate or severe central dislocation of the femoral head treated conservatively is presented in Table 32 In 4 of 6 patients with good reduction of the femoral head and the superior dome intact there were no signs of osteoarthrotic changes In 5 of 6 patients with less satisfactory reduction of the femoral head and the superior dome fractured there were arthrotic changes mild to moderate in one and severe in 4

In 13 patients the superior dome was intact Six of these had no signs of osteoarthrosis (46 per cent) Five patients had mild to moderate and 2 severe arthrotic changes (54 per cent)

In 14 patients the superior dome was fractured Five of these had no signs of osteoarthrosis (36 per cent) Three patients had mild to moderate and 6 severe arthrotic changes (64 per cent)

Posterior fractures (33 patients)

Fourteen patients had radiologic evidence of osteoarthrosis (42 per cent) Nine patients had mild to moderate and 5 severe arthrotic changes In addition 3 patients had necrosis of the femoral head

Table 32 *Correlation between degenerative changes and reduction of the femoral head in 27 patients with varying degree of central dislocation of the femoral head treated conservatively*

Radiologic appearance	Good reduction		Less satisfactory reduction	
	Superior dome intact	Superior dome fractured	Superior dome intact	Superior dome fractured
No signs of osteoarthrotic changes	4	4	2	1
Grade I – osteoarthrosis	2	2	3	1
Grade II – osteoarthrosis	–	2	2	4
	6	8	7	6

CASE REPORTS

Ectopic ossification

Of 99 patients radiologically examined for more than 1 year ectopic ossification was observed in 13 patients (Table 34) Two of these patients had been treated conservatively and 11 surgically The changes usually developed 1-4 weeks after the injury and no special treatment was given

Table 33 *Correlation between clinical results and radiologic findings in 94 hips with acetabular fractures*

Clinical results	No signs of arthrotic changes or necrosis of the femoral head	Grade I Arthrotic changes	Grade II Arthrotic changes	
			without necrosis of the femoral head	with necrosis of the femoral head
Excellent	39	6	1	1
Good	13	7	1	–
Fair	4	5	3	–
Poor	1	2	5	6
	57	20	10	7

Table 34 *Ectopic ossification in 13 patients*

Type of fracture	No of patients	Changes first visible on radiographs	Combined with other radiologic findings	Clinical results
Central fracture with severe dislocation of the femoral head The superior dome fractured treated conservatively	1	4 weeks	grade II	good
Central fracture with severe central dislocation of the femoral head The superior dome fractured treated surgically	4	1 4 weeks	–	fair
		2 2 weeks	grade II	fair
		3 1 year	grade I	good
		4 4 weeks	grade I	fair
Posterior fractures Type II treated surgically	3	1 3 months	–	excellent
		2 3 weeks	grade II	poor
		3 7 years	–	excellent
Type III treated cons	1	4 weeks	–	good
Type III treated surgically	4	1 3 months	grade I	excellent
		2 4 weeks	–	good
		3 1 month	grade II +necrosis	dead
		4 4 years 2 months	grade II +necrosis	dead

CASE REPORTS



A

Fig 20 68 year-old female Fall on the same level A Radiograph at time of injury Central acetabular fracture without dislocation of the femoral head or the acetabular fragments in the left hip Conservative treatment with immobilisation in bed for 1 week B–C Radiographs 2 years and 6 months after injury AP view (B) and Cleave's projection (C) Osteoarthrosis and femoral head necrosis including deformation of a superior section of the femoral head D Radiograph 3 years and 6 months after injury Progress of the osteoarthrosis E Radiograph at follow up 4 years and 4 months after injury Total destruction of the joint Clinical result poor Mobility 4 points



A



C



D



E



A



B

Fig 21 37 year-old male Pedestrian hit by car A Radiograph at time of injury Central acetabular fracture without central dislocation of the femoral head but with displacement of the acetabular fragment in the right hip Conservative treatment with immobilization in bed without traction for 1 month B Radiograph at follow up 10 years after injury No degenerative changes Clinical result excellent Mobility 6 points



A



B



C

Fig ... 34 year-old male Traffic accident Car driver A. Radiograph at time of injury Central acetabular fracture without central dislocation of the femoral head but with displacement of acetabular fragments in the left hip Conservative treatment with immobilization in bed without traction for 4 weeks B–C Radiographs at follow-up 7 years after injury AP view (B) and Cleave's projection (C) The femoral head in its ordinary position. The fracture gap has been filled in with bone No degenerative changes Clinical result good Mobility 6 points



A



B

Fig 21 37 year-old male Pedestrian hit by car A Radiograph at time of injury Central acetabular fracture without central dislocation of the femoral head but with displacement of the acetabular fragment in the right hip Conservative treatment with immobilization in bed without traction for 1 month B Radiograph at follow up 10 years after injury No degenerative changes Clinical result excellent Mobility 6 points



A



B



C

Fig ? 34 year-old male Traffic accident Car driver A. Radiograph at time of injury Central acetabular fracture without central dislocation of the femoral head but with displacement of acetabular fragments in the left hip Conservative treatment with immobilization in bed without traction for 4 weeks B–C: Radiographs at follow-up 7 years after injury AP view (B) and Cleave's projection (C) The femoral head in its ordinary position. The fracture gap has been filled in with bone No degenerative changes Clinical result good Mobility 6 points.



A



B



C



D

Fig 23 47 year-old male Fall from 5 meters A Radiograph at time of injury Central acetabular fracture with moderate central dislocation of the femoral head The superior dome fractured Conservative treatment with traction through the tibial tuberosity for 1 week followed by mobilization without weight bearing for 6 weeks B–D Radiographs at follow up 5 years after injury AP view (B) Cleave's projection (C) and lateral view standing position (D) No degenerative changes Clinical result excellent Mobility 6 points Returned to his original work as a heavy worker 10 weeks after the accident



A



B



C



D

Fig. 24. 24 year-old male. Traffic accident. Car driver. A. Radiograph at time of injury. Central acetabular fracture with severe central dislocation of the femoral head. The superior dome intact. Conservative treatment with combined traction through the tibial tuberosity and the proximal femur for 7 weeks. B. Radiograph 1 month after injury. Good reduction of the femoral head. C. Radiograph 3 months after injury. D. Radiograph at follow-up 6 years and 3 months after injury. Deformed joint. No degenerative changes. Clinical result: excellent. Mobility: 6 points. Works as a sailor.



Fig 25 49 year-old female Fall from 10 meters A Radiograph at time of injury Comminute central acetabular fracture with severe central dislocation of the femoral head The superior dome fractured Conservative treatment with immobilisation in bed without traction for 8 weeks B Radiograph at follow up 8 years and 9 months after injury The femoral head in unchanged position Remodelling of the acetabulum with formation of a new pseudoacetabulum Osteoarthrosis Grade II and ectopic ossification Clinical result good with no pain but a slight limp Mobility 5 points



A



B

C



Fig. 6. 57-year-old female. Pedestrian hit by car. A. Radiograph at time of injury. Central acetabular fracture with severe central dislocation of the femoral head. The superior dome fractured. Conservative treatment with closed reduction under general anesthesia followed by combined traction through the tibial tuberosity and the proximal femur for 13 weeks. B. Radiograph 1 month after injury. Good reduction of the femoral head. C. Radiograph at follow-up 1 year and 6 months after injury. Osteoarthrosis Grade II. Clinical result fair. Mobility 4 points.





B

Fig 27 33 year-old male Traffic accident Car driver A Radiograph at time of injury Central acetabular fracture with severe central dislocation of the femoral head The superior dome fractured Conservative treatment with combined traction through the tibial tuberosity and the proximal femur for 6 weeks
B Radiograph at follow up 2 years and 5 months after injury Remodelling of the acetabulum Osteo arthrosis Grade I Clinical result excellent Mobility 4 points.



A



B



C

Fig. 8. 3-year-old female. Pedestrian hit by car. A. Radiograph at time of injury. Central acetabular fracture with severe central dislocation of the femoral head. The superior dome fractured. Treatment with open reduction and osteosynthesis with three cerclage wires followed by traction through the tibial tuberosity for 6 weeks. B. Radiograph 1 day postoperatively. Good reduction of the femoral head and the acetabular fragments. C. Radiograph at follow-up 4 years after injury. No degenerative changes. Ectopic ossification. Clinical result fair. Mobility 6 points.



A



B

Fig 27 33 year-old male Traffic accident Car driver A *Radiograph at time of injury Central acetabular fracture with severe central dislocation of the femoral head The superior dome fractured Conservative treatment with combined traction through the tibial tuberosity and the proximal femur for 6 weeks*
B *Radiograph at follow up 2 years and 5 months after injury Remodelling of the acetabulum Osteo arthrosis Grade I Clinical result excellent Mobility 4 points*



C



D



E



F



A



B

Fig 29 47 year-old male Traffic accident Car driver A *Radiograph at time of injury Posterior fracture dislocation Type II A large posterior fragment dislocated proximally and posteriorly Conservative treatment with closed reduction of the femoral head followed by traction through the tibial tuberosity for 6 weeks* B *Radiograph after closed recuction of the femoral head The posterior fragment in good position* C–E *Radiographs after 4 years AP view (*C*) No degenerative changes The posterior fragment appears to be redislocated Tomography (*D*) and oblique projection (*E*) show clearly the displacement of the fragment* F *Radiograph at follow-up 7 years and 4 months after injury The fragment is still dislocated No degenerative changes Clinical result good Mobility 6 points*



C



D



E



F



A

Fig 30 31 year-old male Traffic accident Car driver A. *Radiograph at time of injury Posterior fracture dislocation Type II A large posterior fragment dislocated proximally and posteriorly Conservative treatment with closed reduction of the femoral head followed by immobilization in bed without traction for 10 days* B *Radiograph after 1 day The femoral head has been reduced The posterior fragment is still dislocated* C–D *Radiographs at follow-up 11 years and 3 months after injury AP view* (C) *and oblique projection* (D) *The fragment has healed in a dislocated position No degenerative changes Clinical result excellent Mobility 6 points*


B


C


D



A



B



C



D

Fig 31 43 year-old male Fall on the same level A Radiograph at time of injury Posterior fracture-dislocation Type III Surgical treatment with open reduction of the large posterior fragment and fixation with a screw followed by immobilisation in bed for 4 weeks without traction B Radiograph 1 day postoperatively The large posterior fragment has been reduced and fixed with a screw C–D Radiographs 7 years and 2 months after injury (AP view (C) Lateral view standing position (D) Ectopic ossification Osteoarthrosis Grade I Clinical result excellent Mobility 6 points



A



B

C



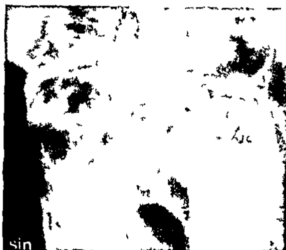
Fig 3... 47 year-old male Traffic accident Car driver A Radiograph at time of injury Posterior acetabular fracture Type III Two large posterior fragments dislocated proximally posteriorly and laterally The femoral head is not dislocated Conservative treatment with immobilization in bed without traction for 7 weeks B–C Radiographs at follow-up ? years after injury AP view (B) and oblique projection (C) The fragments have healed in unchanged positions Osteoarthrosis Grad I Clinical result good Mobility 5 points



A



B



C



D

Fig 31 43 year-old male Fall on the same level A *Radiograph at time of injury Posterior fracture-dislocation Type III Surgical treatment with open reduction of the large posterior fragment and fixation with a screw followed by immobilization in bed for 4 weeks without traction* B *Radiograph 1 day postoperatively The large posterior fragment has been reduced and fixed with a screw* C–D *Radiographs 7 years and 2 months after injury AP view (C) Lateral view standing position (D) Ectopic ossification Osteoarthrosis Grade I Clinical result excellent Mobility 6 points*



A



B

C



Fig 3 47 year-old male Traffic accident Car driver A. Radiograph at time of injury Posterior acetabular fracture Type III Two large posterior fragments dislocated proximally posteriorly and laterally The femoral head is not dislocated Conservative treatment with immobilization in bed without traction for 7 weeks B–C. Radiographs at follow-up ? years after injury AP view (B) and oblique projection (C) The fragments have healed in unchanged positions Osteoarthrosis Grade I Clinical result good Mobility 5 points

Chapter 5

DISCUSSION

Since the earliest description of acetabular fractures with intrapelvic penetration of the femoral head by Callisen 1778 (Schroeder 1909) there has been many reports dealing with these fractures This injury was uncommon before the onset of serious automobile accidents During the first 50 years of the 20th century trauma to the hip became more frequent due to the intensified motor traffic The hip lesion encountered in surgical practice exhibited new features typical of motor-car injuries the damage as a rule being caused by stronger forces than before The most common traumatic mechanism producing *central* acetabular fractures is a blow to the trochanteric region and the injury is mostly sustained in connection with traffic accidents being frequently found among pedestrians In this material the cause of injury was traffic accident in 45 patients Twenty nine of these were pedestrians hit by a car *Posterior* fractures are often the result of motor-car accidents The fracture and fracture-dislocation are frequently caused by a blow applied along the long axis of the femur The mechanism was so often an accompaniment of motor car accidents where the patient s knee struck against the dash-board that the dislocations and fracture-dislocations were given the name of dash-board dislocations (Funsten et al 1938) and dash-board fractures (Waller 1955) In the present material 29 of 39 posterior acetabular fractures were caused by motor-car accidents the patient being either driver or passenger in the car

It is not until the last 20 years that larger series dealing with acetabular fractures have been published making it possible to evaluate the results of different forms of treatment

However fractures of the acetabulum are relatively rare and furthermore individual variations between fractures occur making it difficult to arrive at a simple classification or to outline the management of these patients This absence of a uniform method of classification makes comparisons between materials almost impossible Methods of evaluating results vary greatly and the radiologic criterias used when evaluating the joint following trauma are not uniform

Regarding the classification of *central* acetabular fractures some authors classify their fractures depending on the degree of central dislocation of the femoral head (Stewart & Milford 1954 Bohler 1954 Pearson & Hargadon 1962 Eichenholtz & Stark 1964 Lehtonen 1968) Others have found it more important to take account of the fracture lines and which part of the acetabulum that becomes involved (Knight & Smith 1958 Rowe & Lowell 1961 Judet Judet & Letournel 1964)

This investigation included 30 patients all treated conservatively Twenty-eight were immobilized in bed only and 2 were put into traction Time for immobilization was 2 weeks Twenty seven of 30 i e 90 per cent had excellent or good result which is well comparable with other reported results The results for patients with displacement of the acetabular fragment were even better than for those without displacement All patients with fair or poor result had undisplaced fractures Only 3 of 29 patients radiologically examined showed signs of osteoarthrosis and 2 of these had in addition a necrosis of the femoral head

It seems that acetabular fractures without central dislocation of the femoral head with or without displacement of the acetabular fragment can best be treated by a short period of immobilization in bed

While there is general agreement in the treatment of undisplaced central acetabular fractures there is a diversity of opinion on the treatment of *central acetabular fractures with central dislocation of the femoral head* The surgical treatment of these fractures is difficult (Bohler 1966 Allgower 1966) and there are many who advocate a rather strict conservative line of treatment (Eichenholtz & Stark 1964 Nicoll 1966 Bohler 1966 Tipton et al 1975 Janna 1976) Others advocate surgical treatment Armstrong (1948) recommended early arthrodesis Westerborn (1954) cup arthroplasty and others osteosynthesis with plate and screws (Judet Judet & Letournel 1964 Letournel 1966 Palean & Gualtieri 1971) Even primary total hip replacement has been mentioned in the treatment of these fractures (Coventry 1974) Furthermore some surgeons point out that all central fracture-dislocations should and can best be treated by conservative methods i e longitudinal and lateral traction and perhaps reduction under general anesthesia and recommend open reduction and osteosynthesis only in fractures engaging the superior dome where closed treatment has failed in reducing both the femoral head and the acetabular roof accurately (Rowe & Lowell 1961 Gothlin & Hindmarsh 1970 Carnsale et al 1975)

There is however a general consensus of opinion that the ultimate aim should be as perfect a restoration of the acetabulum femoral head relationship as possible (Gothlin & Hindmarsh 1970 Carnsale et al 1975 Tipton et al 1975) However this is a task sometimes difficult to carry out and incongruity between the articulating surfaces becomes accepted as thus in many cases does not result in impaired function (Rowe & Lowell 1961 Nicoll 1966 Austin 1971 Tipton et al 1975)

This follow up included 36 patients with central acetabular fractures with varying degree of central dislocation of the femoral head Thirty-one patients were treated conservatively and 5 surgically As regards the conservative treatment no strict line of treatment was observed some patients being immobilized in bed only and some being put into traction which in most cases was applied through the tibial tuberosity The superior dome was intact in 15 of the 31 patients conservatively treated and 13 of them i e 87 per cent had excellent or good clinical result No significant difference in clinical results could be observed between those 6 patients who had a good reduction of the femoral head and those 9 who had a less satisfactory reduction In 11 of these 15 patients the dislocation of the femoral head was moderate and in 4 it was severe It is noticeable that those 2 patients who had a severe central dislo-

Judet, Judet & Letournel (1964) have presented a classification based on radiologic examinations including besides AP view also external and internal oblique views in order to determine the anatomy of these fractures as exactly as possible Since the therapeutic approach of these authors is strictly surgical, the aim of their classification and radiologic methods has merely been to study the fracture lines in each case to guide them in open reduction Our approach to the treatment of these fractures has mainly been conservative and in the present study most cases have not been radiologically examined with oblique projections

We have chosen a classification similar to that of Stewart & Milford (1954) based on the degree of central dislocation of the femoral head and the involvement of the weight bearing area i e whether the superior dome was fractured or not

Different classifications have also been presented for *posterior* acetabular fractures Many authors include in their series of posterior fracture-dislocations simple posterior dislocations of the femoral head and posterior dislocations of the femoral head in combination with fractures of the femoral head or the acetabular floor Posterior fracture-dislocations are divided in groups depending on the size and number of posterior fragment(s) the stability of the joint and if in combination with the posterior dislocation a fracture of the femoral head, or the acetabular floor is present (Thompson & Epstein 1951, Stewart & Milford 1954)

In this material we have not included simple posterior dislocations of the femoral head or posterior dislocations of the femoral head combined with fractures of the femoral neck but limited the investigation to posterior acetabular fractures with or without posterior dislocation of the femoral head We have therefore chosen the classification which was presented by Waller in 1955

Since the cause of injury the classification the therapeutic approach and the late results differ between central and posterior acetabular fractures we have in this study chosen to describe these two main groups separately

Central acetabular fractures

There is great confusion in the literature about the treatment of central fracture-dislocations There is a better agreement as regards the treatment of central acetabular fractures without central dislocation of the femoral head This investigation has included central acetabular fractures without central dislocation of the femoral head as well as central fractures with central intrapelvic protrusion of the femoral head

In order to minimize the examiner s subjective opinion a point system suggested by d Aubigné & Postel 1954 later modified by Charnley in 1972 was followed at the assessment of results A summary of the points for pain and walking has been made to facilitate a comparison with other reported results and between clinical results and radiologic appearance

Central fractures without central dislocation of the femoral head usually offer no problems These fractures are generally treated by conservative methods Some recommend bed rest only (Rowe & Lowell 1961 Judet Judet & Letournel 1964 Solheim & Skrede 1973) and others a short period of traction (Wechselberger 1956 Pearson & Hargadon 1962 Eichenholtz & Stark 1964) Excellent or good results in 90 to 100 per cent are reported by Rowe & Lowell and Eichenholtz & Stark

This investigation included 30 patients all treated conservatively Twenty-eight were immobilized in bed only and 2 were put into traction Time for immobilization was 2 weeks Twenty-seven of 30 i e 90 per cent had excellent or good result which is well comparable with other reported results The results for patients with displacement of the acetabular fragment were even better than for those without displacement All patients with fair or poor result had undisplaced fractures Only 3 of 29 p tients radiologically examined showed signs of osteoarthrosis and 2 of these had in addition a necrosis of the femoral head

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cation and a less satisfactory reduction of the femoral head both had excellent results Thirteen of the 15 patients were radiologically examined and 7 of them had osteoarthrosis (54 per cent) (2 of the 6 patients with good reduction of the femoral head and 5 of the 7 patients with less satisfactory reduction of the femoral head) Our results are in accordance with the results of Rowe & Lowell (1961), Gothlin & Hindmarsh (1970) and N^rubay et al (1973) who found 70 to 90 per cent excellent or good results in innerwall fractures treated conservatively It seems that these fractures can be adequately treated with conservative methods i e longitudinal and lateral traction for 6 8 weeks *If traction fails in reducing the femoral head* an attempt during general anesthesia should be performed It seems that anatomical reduction of the acetabular fragments is of less importance in these fractures The important thing is to reduce the femoral head under the acetabular roof and keep it there Like Rowe & Lowell Eichenholtz & Stark and Austin we found that traction usually had little effect in reducing the *acetabular fragments but yet it seemed that nature had filled in* the gap between the femoral head and the acetabular fragments so that a smooth congruent socket had developed

Sixteen patients of the 31 with central fracture-dislocations treated conservatively had the superior dome fractured Late results were not so good in this group, and only 38 per cent had excellent or good clinical results Good reduction of the femoral head (8 patients) gave better results than less satisfactory reduction (8 patients) Worst results were seen in the 9 patients who had a severe central dislocation of the femoral head Fourteen patients were radiologically examined and 9 of them i e 64 per cent had osteoarthrosis (4 of the 8 patients with good reduction and 5 of the 6 patients with less satisfactory reduction) The present results are similar to those of Rowe & Lowell who found 36 per cent excellent or good results in superior dome fractures

Only 5 patients were treated surgically all had central fractures with severe central dislocation of the femoral head with the fracture engaging the superior dome Only one patient achieved a good clinical result In only 2 patients the femoral head was reduced

Analysis of the results in the present series show similarities to other reported results Fractures of the inner wall both with moderate and severe central dislocation of the femoral head gave excellent or good clinical results in the majority of cases with conservative treatment

Central fracture-dislocations with fractures or the acetabular roof in which the femoral head and the superior dome are satisfactorily reduced by traction or manipulation can be adequately treated by conservative methods When however closed treatment has failed in reducing the femoral head and the acetabular roof accurately primary open reduction appears to be a rational approach to the problem It is in line with the modern principles of management of intraarticular fractures especially in weightbearing joints because it is aimed at restoring congruity of the weightbearing articular surfaces However it is a major undertaking the technique is difficult and demands considerable surgical experience and not all patients requiring treatment will be found to be suitable for it Major associated head and chest injuries severe chock severe comminution of the fracture and advanced age may all contraindicate this form of treatment Apart from these limitations on the use of open reduction as a standard method of treatment there are other points that should not be forgotten

it is never possible to make an accurate assessment of the damage of the articular cartilage possibly caused by the injury Because such damage may be a major contributory factor in determining the development of later osteoarthrosis or femoral head necrosis simple restoration of the anatomy of the acetabulum may not be adequate Furtheron Porter (1973) and Batra (1976) have stated that for technical reasons accurate reduction at operation is not always possible and therefore joint congruity may not be achieved in a proportion of patients Letournel (1966) in his series of 170 operated patients (including 42 posterior fractures) described perfect reduction of the acetabular fragments in 62 per cent and perfect reduction of the femoral head in 85 per cent

It is difficult to state categorically the indications for open reduction and each case must be considered on its own merits However we agree with Carnsale et al (1975) and Batra (1976) that in relatively young patients who have displaced fractures with involvement of the roof without undue comminution this line of treatment may be considered desirable in the hope of reducing displacement and preventing deformity and such premature degeneration in the hip joint as may result solely from uncorrected deformity

Posterior fractures

While there is confusion about the treatment of central fracture-dislocations there seems to be greater unity regarding the treatment of posterior fracture-dislocations The posterior part of the acetabulum has not a weightbearing function but has merely a stabilizing effect on the joint Most authors agree that a posterior dislocation of the femoral head should be regarded as an emergency and the dislocation should be reduced acute (Stewart & Milford 1954 Waller 1955 Brav 1962 Epstein 1974 Ender 1976) Posterior acetabular fractures without posterior dislocation of the femoral head and without displacement of the acetabular fragment(s) are generally treated by conservative methods i e immobilization in bed or traction for a few weeks (Waller 1955 Nicoll 1966) In posterior fracture-dislocations the important thing is that the dislocated femoral head is reduced to its normal position and is kept there There is an absolute indication for operation when the femoral head cannot be brought to its normal position by conservative methods i e manipulation during general anesthesia or when there is an involvement of the sciatic nerve (Waller 1955 Rowe & Lowell 1961 Brav 1962 Nicoll 1966 Epstein 1974 Ender 1976) Most authors agree that instability of the joint after reduction of the femoral head requires surgical exploration and osteosynthesis of the acetabular fragment (Rowe & Lowell 1961 Brav 1962 Stewart et al 1975 Ender 1976) The instability is demonstrated at the time of reducing the dislocation (Nicoll 1966 Ender 1976) If the joint is regarded as stable after reduction of the femoral head but a posterior fragment remains displaced some advocate surgical treatment (Waller 1955 Epstein 1974 Ender 1976) and others conservative treatment (Bohler 1954 Brav 1962 Nicoll 1966)

In this material 3 patients had posterior fractures with a small to moderate undisplaced fragment All were treated conservatively with immobilization in bed for 1 2 weeks and all had excellent clinical results It appears that these fractures can best be treated by immobilization in bed for 1 2 weeks

cation and a less satisfactory reduction of the femoral head both had excellent results Thir teen of the 15 patients were radiologically examined and 7 of them had osteoarthrosis (54 per cent) (2 of the 6 patients with good reduction of the femoral head and 5 of the 7 patients with less satisfactory reduction of the femoral head) Our results are in accordance with the results of Rowe & Lowell (1961) Gothlin & Hindmarsh (1970) and Nerubay et al (1973) who found 70 to 90 per cent excellent or good results in innerwall fractures treated conserva tively It seems that these fractures can be adequately treated with conservative methods i e longitudinal and lateral traction for 6 8 weeks If traction fails in reducing the femoral head an attempt during general anesthesia should be performed It seems that anatomical reduction of the acetabular fragments is of less importance in these fractures The important thing is to reduce the femoral head under the acetabular roof and keep it there Like Rowe & Lowell, Lichenholtz & Stark and Austin we found that traction usually had little effect in reducing the acetabular fragments but yet it seemed that nature had filled in the gap between the femoral head and the acetabular fragments so that a smooth congruent socket had developed

Sixteen patients of the 31 with central fracture dislocations treated conservatively had the superior dome fractured Late results were not so good in this group and only 38 per cent had excellent or good clinical results Good reduction of the femoral head (8 patients) gave better results than less satisfactory reduction (8 patients) Worst results were seen in the 9 patients who had a severe central dislocation of the femoral head Fourteen patients were radiologically examined and 9 of them i e 64 per cent had osteoarthrosis (4 of the 8 patients with good reduction and 5 of the 6 patients with less satisfactory reduction) The present re sults are similar to those of Rowe & Lowell who found 36 per cent excellent or good results in superior dome fractures

Only 5 patients were treated surgically all had central fractures with severe central dislo cation of the femoral head with the fracture engaging the superior dome Only one patient achieved a good clinical result In only 2 patients the femoral head was reduced

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Epstein (1974) had even less good results for patients treated conservatively namely 14 per cent whereas he had 44 per cent good results for patients treated by closed reduction of the femoral head followed by open reduction and osteosynthesis of the acetabular fragment In his material 50 per cent of the patients treated conservatively had unfavourable features of the kind mentioned above However Nicoll (1966) points out that excellent results should be attainable in all posterior fracture-dislocations and only 1/3 will require operation either to restore stability or to remove obstructing fragments Stewart et al (1975) reported on 57 patients with conservatively treated posterior acetabular fractures (Type II III) and 39 (68 per cent) had excellent or good results In 44 patients the posterior dislocation was reduced within 12 hours and this group of patients included all those who had excellent or good results In the present series 8 patients had poor results and 5 of these had unfavourable features i e redislocation of the femoral head unreduced dislocation or combination with a central fracture

Osteoarthrosis and femoral head necrosis are sequela which as a rule result in impaired function and it cannot be excluded that the fate of the fracture is decided at the time of injury Most authors agree that the cause of avascular necrosis is a disturbed circulation due to injury to the ligament of the femoral head and to the joint capsule in fracture-dislocations (Waller 1955 Elliott 1956 Stewart et al 1975) When the head of the femur becomes dislocated out of the joint cavity the ligamentum teres always ruptures totally which was proved experimentally by Waller (1955) Even if only some of the vessels in the posterior part of the capsule are divided when the femoral head dislocates the circulation in the tightly stretched out capsule is endangered as surviving vessels tend to become compressed and thrombotic Early reduction of the dislocation is of the greatest importance for these reasons (Waller 1955 Elliott 1956) However necrosis of the femoral head and arthrotic changes sometimes develop after trauma in which the hip has not been dislocated – indeed it may even develop without any known injury Consequently it is possible that avascular necrosis after fracture dislocation of the hip is not always caused by destruction of the circulation through the ligamentum teres and the posterior part of the capsule Stewart & Milford (1954) suggested that the force of the injury may be important in determining whether avascular necrosis develops In this type of injury it is reasonable to believe that both the head of the femur and the acetabulum itself sustain damage Radiologically and clinically the head of the femur does not usually show damage unless a piece of bone has been fractured off the head which occurs rarely (Elliott 1956) However a force resulting in an impact to the femoral head may perhaps cause intracellular molecular changes resulting in necrosis of bone as suggested by Stewart & Milford (1954)

Thirty two patients had posterior fractures classified as Type II or III 14 were treated conservatively, 18 surgically Our indications for surgery have been

1 Remaining displacement of the acetabular fragment(s) (Reports from the patient records regarding stability or instability have not been obtained) Most of the patients were operated upon within 1 week
2 Redislocation of the femoral head
3 Unsuccessful closed reduction
4 Sciatic nerve involvement

Postoperatively some were put into traction and others were immobilized in bed only Time for immobilization was 4 6 weeks The conservative treatment has included closed reduction of the femoral head under general anesthesia and immobilization in bed with or without traction for 3 5 weeks Of the patients treated conservatively 79 per cent had excellent or good clinical results and of the patients treated surgically 67 per cent had excellent or good results (Type II treated conservatively 100 per cent excellent or good Type II treated surgically 70 per cent excellent or good, Type III treated conservatively 67 per cent excellent or good Type III treated surgically 63 per cent excellent or good)

In 8 patients the posterior acetabular fragment remained displaced after reduction of the femoral head The clinical results were as good for these patients as for the others treated conservatively Thirty two patients with posterior fracture-dislocations of Type II or III were included in the radiologic follow up study Osteoarthrosis and femoral head necrosis were more frequently seen in the patients who had been operated upon (Tables 30 and 31)

The clinical results in this series are in accordance with other reports The results for patients treated conservatively are similar to those of Brav (1962) Nerubay et al (1973) and Stewart et al (1975) who found 60 to 80 per cent excellent or good long term results after conservative treatment of these fractures The results for patients treated surgically are similar to those of Waller (1955) Rowe & Lowell (1961) Brav (1962) Solheim & Skrede (1973) and Stewart et al (1975) who found 60 to 75 per cent excellent or good long term results after surgical treatment

Most important in posterior fracture-dislocations seems to be the reduction of the femoral head and the stability of the joint If these demands can be fulfilled and there is no sciatic nerve palsy the prognosis for these fractures seems to be independent of whether they are treated conservatively or surgically The bad results obtained both after conservative and surgical treatment often depend on the above demands not having been fulfilled For example 1 The posterior dislocation has been missed and the femoral head has not been reduced until after 24 hours In some cases there has been no reduction at all 2 Repeated unsuccessful attempts with closed reduction have been made 3 Redislocation of the femoral head has occurred due to instability

Waller (1955) had only 21 per cent excellent or good results in his patients with Type II and III fractures who had been treated conservatively

5 If the joint is regarded as stable after closed reduction of the femoral head but a moderate to large fragment is still dislocated and there are signs of sciatic nerve involvement open reduction and osteosynthesis should be performed If however there is no sign of nerve injury the prognosis is probably not determined of whether these fractures are operated or not

6 If the femoral head has not been dislocated posteriorly and the fragment remains in its place conservative treatment with immobilization in bed for a short period is adequate

CONCLUSION

It is difficult to state cathegorically the line of treatment for these fractures Age and associated injuries have to be considered when deciding about treatment However the following general conclusions can be made based on this study and on the study of the literature

Central acetabular fractures

1 For a detailed analysis of these fractures the radiologic examination should include besides AP views even oblique views
2 Central acetabular fractures without central dislocation of the femoral head can be adequately treated by a short period of immobilization in bed
3 Central acetabular fractures with central dislocation of the femoral head but without fracture of the superior dome can be treated conservatively with traction through the tibial tuberosity possibly in combination with lateral traction applied through the proximal femur If traction fails in reducing the femoral head under the intact acetabular roof an attempt during general anesthesia should be made The traction is continued for 6 8 weeks
4 In central acetabular fractures with central dislocation of the femoral head and fracture of the superior dome an attempt at conservative treatment with traction should be made General anesthesia may be required for reduction If conservative treatment fails in reducing the femoral head and the acetabular roof accurately open reduction and osteosynthesis can be considered especially in young patients without undue comminution of the fracture

Posterior acetabular fractures

1 A posterior dislocation of the femoral head should be treated as an emergency and acute reduction should be performed
2 After reduction the radiologic examination should include AP lateral and oblique projections
3 When closed reduction fails in reducing the femoral head open reduction of the femoral head and osteosynthesis of the acetabular fragment should be made
4 If instability can be demonstrated at the time of closed reduction of the femoral head the acetabular fragment should be fixed

5 If the joint is regarded as stable after closed reduction of the femoral head but a moderate to large fragment is still dislocated and there are signs of sciatic nerve involvement open reduction and osteosynthesis should be performed If however there is no sign of nerve injury the prognosis is probably not determined of whether these fractures are operated or not

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PART TWO

AN EXPERIMENTAL STUDY

by

Olle Lansinger and Bertil Romanus

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INTRODUCTION

The knowledge of the fracture mechanism of central acetabular fractures is mainly based on clinical observations

Some experimental studies have been made on cadavers violent forces being directed to the trochanteric region by hammers, falling weights or a pendulum The position of the femoral neck in relation to the acetabulum has not been registered Analysis of this position and its possible importance in the production of varying types of acetabular fractures has thus not been possible

The purpose of this investigation has been to design an experimental model by which central acetabular fractures can be produced on cadaver pelves and to determine the conditions (energy and position of the hip joint) under which various types of central acetabular fractures can be produced (fractures of the posterior column transverse fractures and fractures of the anterior column)

Fracture mechanism

Theories based on clinical materials

Central acetabular fractures are believed to result from a direct blow to the trochanteric region as occurs e g when pedestrians become knocked down by a car or in falls from heights

The fracture mechanism has been analysed by Cauchoix & Truchet (1951) Wollmar & Wachtler (1956) Judet et al (1964) and Judet & Letournel (1974)

Cauchoix & Truchet (1951) suggested that depending on the degree of rotation of the femur with this in extension fractures arise either anteriorly or posteriorly in the acetabulum when a force is directed to the greater trochanter Excluding the view on the importance of the rotation of the femur Wollmar & Wachtler (1956) pointed to the importance of the force being transmitted via the femoral neck and the importance of the femoral head being well centered in the acetabulum.

Judet et al (1964) and Judet & Letournel (1974) described the theoretical background for posterior rim fractures fractures of the posterior and anterior column and transverse fractures With a force directed to the trochanteric region of the extended hip transverse and posterior fractures were calculated to arise when the femoral neck was internally rotated 50° transverse fractures when it was internally rotated 0 – 50° fractures of the anterior column when it was externally rotated 0 – 25° and fractures of the anterior lip when it was externally rotated 50° With the hip joint flexed 90 and with the force acting along the femur fractures would arise in the posterior rim posterior lip or the posterior column or transverse fractures would arise depending on the degree of abduction and adduction

Previous experimental studies on acetabular fractures

Central acetabular fractures have been produced by Virveaux (1899) Thévenot (1904) Schroeder (1909) Cottalorda (1922) Romani (1928) Cauchoix & Truchet (1951) Creyssel & Schnepp (1961) and Pearson & Hargadon (1962) (Table 35)

Table 35 Earlier experimental works on central acetabular fractures

Author	Reported experiments	Reported acetabular fractures	Fractures of the femoral neck or shaft
Virveaux 1899	17	4	4
Schroeder – 1909	14	4	8
Cottalorda 1922	7	4	
Romani 1928	22	3	11
Creyssel & Schnepp – 1961	12	5	
Pearson & Hargadon 1962	11	11	

Cauchoix & Truchet (1951) stated that it was necessary with a violent force and a solid femoral neck to produce experimental acetabular fractures. They suggested that different degrees of rotation of the femur resulted in different types of fractures when blows were directed to the trochanteric region

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Pearson & Hargadon 1962	11	11	

Cauchoix & Truchet (1951) stated that it was necessary with a violent force and a solid femoral neck to produce experimental acetabular fractures. They suggested that different degrees of rotation of the femur resulted in different types of fractures when blows were directed to the trochanteric region

A blow has been directed to the trochanteric region of whole cadavers with a hammer or a wooden club (Virveaux 1899 Schroeder 1909, Cottalorda 1922 Romani 1928), with a falling weight (Creyssel & Schnepp 1961), or with a pendulum (Pearson & Hargadon 1962) Attempts have not been made to produce these fractures by blows in the direction of the femoral neck axis The exact point for the hit has not been registered and the position of the hip joint at the moment of the blow and the importance of this position for the production of various fracture types have not been analysed

Posterior acetabular fractures have been produced on cadavers by Waller (1955) In 160 experiments he produced 108 posterior "dashboard ' fractures by a falling weight (60 kg from 2 meters) against the knee with the hip and the knee in flexion He described the conditions under which these fractures could be produced

Table 36 Pelvic specimens (F = female M = male)

Specimen	Experiment	Age and sex	Height cm	Weight kg	Cause of death
1	1	59 F	–	–	Circulatory insuff
2	2	56 F	–	–	Liver insuff
3	3	49 M	183	72	Circulatory insuff
4	4 + 5	66 F	165	53	Circulatory insuff
5	6 + 7	61 F	162	49	Circulatory insuff
6	8	78 F	166	42	Circulatory insuff
7	9 + 10	–	–	–	–
8	11 + 12	–	–	–	–
9	13 + 14	–	–	–	–
10	15 + 16	76 F	158	49	Circulatory insuff
11	17 + 18	–	–	–	–
12	19 +20	–	–	–	–
13	21 +22	–	–	–	–
14	23 +24	–	–	–	–
15	25 +26	27 M	184	73	Chron glomerulonephritis
16	27 +28	85 M	–	–	Circulatory insuff
17	29 +30	77 M	194	97	Cancer of the colon
18	31 +32	57 M	175	64	Circulatory insuff
19	33 +34	60 M	–	–	Cancer of the lung
20	35 +36	72 M	179	83	Circulatory insuff
21	37 +38	59 F	160	50	Cancer of the lung
22	39 +40	79 F	154	47	Circulatory insuff
23	41 +42	60 F	–	–	Circulatory insuff
24	43 +44	74 M	–	–	Circulatory insuff

– / Information missing

Material

Twenty four cadaver pelves were used (Table 36) They consisted of the pelvic ring with the fifth lumbar vertebra and the proximal 15 – 20 centimeters of both femora The specimens were roughly cleaned from soft tissues except for the ligaments which were left intact The cadaver pelves were all from individuals who had died from non skeletal diseases mainly cardiovascular There was osteoarthrosis in two hips one of which had been operated with an osteotomy The remaining pelves were all radiographically normal The known age distribution of the individuals was 27 – 85 years It was not possible in all to establish the exact duration of premortal bed-rest or the height and weight from the medical records

The specimens were either used on the day of preparation or stored in a deep freeze (–20° C) and thawed at room temperature 12 – 24 hours prior to the experiment

Method

The specimens were divided into two parts in a sagittal plane through the middle of the vertebra L 5 the sacrum and the coccyx. Anteriorly the division was carried through the symphysis The resected surfaces were fixed in a metal box (31 x 18 x 4 centimeters) with epoxy resin (Plastic Padding®) The metal box was screwed onto a stand which was adjustable (Figs 33 and 34)

One object of these experiments has been to transmit the force of the pendulum along the femoral neck axis Another has been to define the degrees of rotation abduction and adduction of the femur for each individual test To achieve this adjustments of the position of the specimen had to be done and the exactness was determined by radiologic examination of the specimen set-up in 2 perpendicular planes prior to each experiment

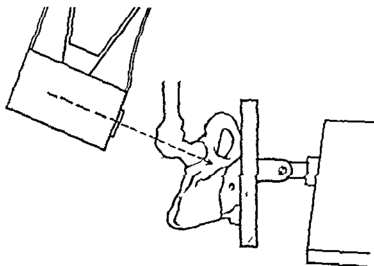


Fig 33 Experimental set-up in experiments with the femur in extension (left hip)

Energy

The greater trochanter was subjected to a blow by a pendulum with its centre in the ceiling and with a radius of 225 centimeters and a weight of 35 kilos The fall varied from 45 – 140 centimeters corresponding to an energy of 155 – 480 Nm

A total of 44 experiments was performed the first 32 with the femur in extension and the last 12 with the femur in 60 – 90° flexion With extension we mean that the femoral shaft is paralell to a plane through the anterior superior iliac spine and the pubic crest (Boyd et al 1958)

Definitions

Measurements of the position of the femur the striking point of the pendulum and the direction of its force were done on radiographs 3 perpendicular planes were used sagittal frontal and transverse The metal box acted as a sagittal plane

The femoral neck axis The centre of the femoral head has been determined by concentric circles A line has been drawn from the centre of the femoral head to the midpoint of the border between the femoral head and neck This line has been called the femoral neck axis (Figs 35 and 36)

The longitudinal axis of the femur This has been determined on radiographs by drawing a line through the centre of the femoral shaft

Radiologic determination of the position of femur

The angle of anteversion of the femoral neck is estimated at between 12 – 14° (Rydell 1966) The individual variation is great (–13 to 55°) (Backman 1957) To determine the angle of anteversion it is necessary to have the complete femur For this study however the degree of rotation of the femoral neck has been determined by the degree the femoral neck axis

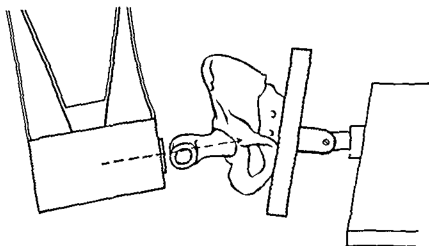


Fig 34 Experimental set up in experiments with the femur in flexion (right hip)

formed in relation to the frontal plane (in experiments with the femur in extension) and to the transverse plane (with the femur in 90° flexion)

The position of the femur has been defined in the following projections

Experiments with the femur in extension

In the *vertical view* of the specimen (Fig 35) the angle between the axis of the femoral neck and a frontal plane was determined

+ indicates that the femoral neck axis forms an angle posterior to the frontal plane "external rotation" (Fig 35 A)
– indicates that the femoral neck axis forms an angle anterior to the frontal plane "internal rotation (Fig 35 B)

In the *AP (anteroposterior) view* of the specimen the degree of abduction and adduction in relation to the sagittal plane was determined (Fig 33)

Experiments with the femur in flexion

In the *AP view* of the specimen (Fig 34) the angle between the femoral neck axis and a transverse plane was determined (Fig 36)

+ indicates that the femoral neck axis forms an angle inferior to the transverse plane "ex

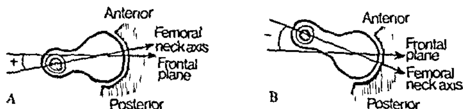


Fig 35 Vertical view of the right hip with the femur in extension (perpendicular to the paper plane) A + indicates that the femoral neck axis forms an angle posterior to the frontal plane ("external rotation") B – indicates that the femoral neck axis forms an angle anterior to the frontal plane ("internal rotation")

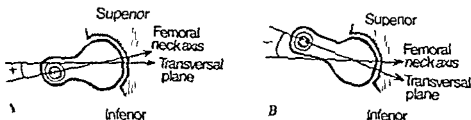


Fig 36 AP view of right hip with the femur in 90° flexion (perpendicular to the paper plane) A + indicates that the femoral neck axis forms an angle inferior to the transverse plane ("external rotation") B – indicates that the femoral neck axis forms an angle superior to the transverse plane ("internal rotation")

ternal rotation (Fig 36 A)
– indicates that the femoral neck axis forms an angle superior to the transverse plane in ternal rotation (Fig 36 B)

In the *vertical view* of the specimen the degree of abduction and adduction in relation to the sagittal plane was determined

Position of the femur (Tables 37 38 and 40)

In 32 experiments the femur was positioned in extension the degree of combined external or internal rotation was varied In 12 experiments the femur was positioned in flexion the degree of combined abduction or adduction was varied In 7 of these experiments the degree of flexion was 85 – 90° and in 5 60 – 75°

Preliminary study

Based on the reports of previous experimental work and on the theories of the fracture mechanism in central acetabular fractures a preliminary study of 12 experiments was carried out (experiments 1 – 12) (Table 37)

Set up of specimen The pelvic specimen was placed on the stand upside down with the hip joint extended (Fig 33) In the first 8 experiments the pendulum hit the greater trochanter at the lowest point of the pendulum course In the following 4 experiments the blow was directed to the trochanter before the lowest point of the pendulum course as it in this way was easier to obtain the force along the femoral neck axis The energy the direction of force and the position of the hip joint varied (Table 37)

Results of the preliminary study (Table 37)

In experiments 1 3 6 and 7 the blow hit the trochanter with the force directed inferior to the femoral neck axis resulting in a valgus effect This resulted in pertrochanteric fractures in experiments 1 6 and 7 In experiments 6 and 7 transverse acetabular fractures were also achieved and in experiment 3 a posterior column fracture was obtained In experiment 4 the blow hit the trochanter with the force posterior to the femoral neck axis and a femoral neck fracture and an anterior column fracture were produced In experiments 5 8 and 9 the force was transmitted ideally as checked in the AP and vertical projections in experiment 5 a T fracture was produced in experiment 8 a transverse fracture and in experiment 9 a posterior column fracture In specimen 6 (experiment 8) an intertrochanteric osteotomy according to Wainwright had been carried out In this case there was a coxa vara which facilitated the blow in the direction of the femoral neck axis In this experiment an axial compression fracture of the femoral neck was also produced

In experiment 9 an attempt was made to stabilize the hip joint by a Kirschner wire passed along the femoral neck axis into the acetabulum After the pendulum hit it was noted that an abduction of 35° had occurred as indicated by bending of the wire In experiments 10 11 and 12 we tried to stabilize the hip joint by not thawing the specimens completely The force was in these experiments transmitted ideally along the femoral neck axis A pertrochanteric

Table 37 Experimental acetabular fractures – hip in extension Preliminary study

Ex peri ment	Energy (Nm)	Position of femur: Abduction (Abd) or adduction (Add) degrees	Position of femur: Rotation degrees	Result: Acetabular fracture	Result: Femoral neck or pertrochanteric fractur	Remarks
1	155	–	–	–	Pertrochanteric	
2	258	–	–	Vertical fracture line anteriorly		
3	430		–	Posterior column	–	
4	430	Abd 4	+ 10	Anterior column	Femoral neck	
5	430	Add 4	+ 17	T-fracture	–	
6	430	Abd 5	– 10	Transverse	Pertrochanteric	
7	430	Add 10	– 10	Trans erse	P rtrochanteric	
8	430	Add 6	+ 15	Transverse	Femoral neck	o teoarthro is
9	430	Add 10	+ 8	Posterior column		
10	310	Add 18	+ 16	–		not fully thawed
11	310	Add 10	+ 9	–	Pertrochanteric	not fully thaw d
12	310	Add 20	+ 4	Vertical fracture line po teriorly	–	not fully thawed

compression fracture was produced in one experiment (11) and a vertical fracture line posteriorly in the acetabulum in another (12) There were no other fractures in the acetabulum or pelvis probably owing to a change of the physical properties (e.g stiffness of the soft tissues)

Nine fractures were produced in 12 experiments in this preliminary study Three were transverse fractures with only a fracture line through the middle of the acetabulum One was a T-fracture through the anterior and posterior columns Two were anterior fractures one of whi h was a fracture of the anterior column and the other only a vertical fracture line anteriorly Three were fractures po teriorly in 2 of which the posterior column was fra tured In one there was only a fracture line posteriorly The femoral head was not dislocated entrally in any experiment

Conclusion of the preliminary study

This preliminary study gave the conditions necessary for the best position of the specimen to produce an acetabular fracture with the pendulum hitting the trochanter with the hip joint in extension It was found necessary to strike the femoral neck in an axial direction to avoid pertrochanteric and femoral neck fractures The femur had in these 12 preliminary experiments been fixed with silk sutures in the soft tissues in experiments 1 – 8 been transfixed by a Kirschner wire in experiment 9 and been half thawed in experiments 10 – 12 To obtain a better centering of the femoral head and also a stabilization of the femur in the further experiments strings were threaded through canals drilled in the femur and the iliac wing and through the obturator foramen in directions corresponding to normal muscles

ternal rotation (Fig 36 A)

– indicates that the femoral neck axis forms an angle superior to the transverse plane in ternal rotation (Fig 36 B)

In the *vertical view* of the specimen the degree of abduction and adduction in relation to the sagittal plane was determined

Position of the femur (Tables 37 38 and 40)

In 32 experiments the femur was positioned in extension the degree of combined external or internal rotation was varied In 12 experiments the femur was positioned in flexion the degree of combined abduction or adduction was varied In 7 of these experiments the degree of flexion was 85 – 90° and in 5 60 – 75°

Preliminary study

Based on the reports of previous experimental work and on the theories of the fracture mechanism in central acetabular fractures a preliminary study of 12 experiments was carried out (experiments 1 – 12) (Table 37)

Set up of specimen The pelvic specimen was placed on the stand upside down with the hip joint extended (Fig 33) In the first 8 experiments the pendulum hit the greater trochanter at the lowest point of the pendulum course In the following 4 experiments the blow was directed to the trochanter before the lowest point of the pendulum course as it in this way was easier to obtain the force along the femoral neck axis The energy the direction of force and the position of the hip joint varied (Table 37)

Results of the preliminary study (Table 37)

In experiments 1 3 6 and 7 the blow hit the trochanter with the force directed inferior to the femoral neck axis resulting in a valgus effect This resulted in pertrochanteric fractures in experiments 1 6 and 7 In experiments 6 and 7 transverse acetabular fractures were also achieved and in experiment 3 a posterior column fracture was obtained In experiment 4 the blow hit the trochanter with the force posterior to the femoral neck axis and a femoral neck fracture and an anterior column fracture were produced In experiments 5 8 and 9 the force was transmitted ideally as checked in the AP and vertical projections in experiment 5 a T fracture was produced in experiment 8 a transverse fracture and in experiment 9 a posterior column fracture In specimen 6 (experiment 8) an intertrochanteric osteotomy according to Wainwright had been carried out In this case there was a coxa vara which facilitated the blow in the direction of the femoral neck axis In this experiment an axial compression fracture of the femoral neck was also produced

In experiment 9 an attempt was made to stabilize the hip joint by a Kirschner wire passed along the femoral neck axis into the acetabulum After the pendulum hit it was noted that an abduction of 35° had occurred as indicated by bending of the wire In experiments 10 11 and 12 we tried to stabilize the hip joint by not thawing the specimens completely The force was in these experiments transmitted ideally along the femoral neck axis A pertrochanteric

Table 37 Experimental acetabular fractures – hip in extension Preliminary study

Ex peri ment	Energy (Nm)	Position of femur: Abduction (Abd) or adduction (Add) degrees	Rotation degrees	Result: Acetabular fracture	Femoral neck or pertrochanteric fracture	Remarks
1	155	–	–	–	Pertrochanteric	
2	258	–	–	Vertical fracture line anteriorly	–	
3	430	–	–	Posterior column	–	
4	430	Abd 4	+10	Anterior column	Femoral neck	
5	430	Add 4	+17	T-fracture	–	
6	430	Abd 5	–10	Transverse	Pertrochanteric	
7	430	Add 10	–10	Transverse	Pertrochanteric	
8	430	Add 6	+15	Transverse	Femoral neck	osteoarthrosis
9	430	Add 10	+8	Posterior column	–	
10	310	Add 18	+16	–	–	not fully thawed
11	310	Add 10	+9	–	Pertrochanteric	not fully thawed
12	310	Add 0	+4	Vertical fracture line posteriorly	–	not fully thawed

compression fracture was produced in one experiment (11) and a vertical fracture line posteriorly in the acetabulum in another (12) There were no other fractures in the acetabulum or pelvis probably owing to a change of the physical properties (e g stiffness of the soft tissues)

Nine fractures were produced in 12 experiments in this preliminary study Three were transverse fractures with only a fracture line through the middle of the acetabulum One was a T-fracture through the anterior and posterior columns Two were anterior fractures one of which was a fracture of the anterior column and the other only a vertical fracture line anteriorly Three were fractures posteriorly in 2 of which the posterior column was fractured In one there was only a fracture line posteriorly The femoral head was not dislocated centrally in any experiment

Conclusion of the preliminary study

This preliminary study gave the conditions necessary for the best position of the specimen to produce an acetabular fracture with the pendulum hitting the trochanter with the hip joint in extension It was found necessary to strike the femoral neck in an axial direction to avoid pertrochanteric and femoral neck fractures The femur had in these 12 preliminary experiments been fixed with silk sutures in the soft tissues in experiments 1 – 8 been transfixed by a Kirschner wire in experiment 9 and been half thawed in experiments 10 – 12 To obtain a better centering of the femoral head and also a stabilization of the femur in the further experiments strings were threaded through canals drilled in the femur and the iliac wing and through the obturator foramen in directions corresponding to normal muscles

ternal rotation ' (Fig 36 A)

– indicates that the femoral neck axis forms an angle superior to the transverse plane, internal rotation ' (Fig 36 B)

In the *vertical view* of the specimen the degree of abduction and adduction in relation to the sagittal plane was determined

Position of the femur (Tables 37, 38 and 40)

In 32 experiments the femur was positioned in extension the degree of combined external or internal rotation was varied In 12 experiments the femur was positioned in flexion the degree of combined abduction or adduction was varied In 7 of these experiments the degree of flexion was 85 – 90° and in 5 60 – 75°

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Based on the reports of previous experimental work and on the theories of the fracture mechanism in central acetabular fractures a preliminary study of 12 experiments was carried out (experiments 1 – 12) (Table 37)

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In experiment 9 an attempt was made to stabilize the hip joint by a Kirschner wire passed along the femoral neck axis into the acetabulum After the pendulum hit it was noted that an abduction of 35° had occurred as indicated by bending of the wire In experiments 10 11 and 12 we tried to stabilize the hip joint by not thawing the specimens completely The force was in these experiments transmitted ideally along the femoral neck axis A pertrochanteric

Table 37 Experimental acetabular fractures – hip in extension Preliminary study

Experiment	Energy (Nm)	Position of femur: Abduction (Abd) or adduction (Add) degrees	Rotation degrees	Result: Acetabular fracture	Femoral neck or pertrochanteric fracture	Remarks
1	155	–	–	–	Pertrochanteric	
2	58	–	–	Vertical fracture line anteriorly	–	
3	430	–	–	Posterior column	–	
4	430	Abd 4	+10	Anterior column	Femoral neck	
5	430	Add 4	+17	T–fracture	–	
6	430	Abd 5	– 10	Transverse	Pertrochanteri	
7	430	Add 10	– 10	Transverse	Pertrochanteric	
8	430	Add 6	+15	Transverse	Femoral neck	osteoarthrosis
9	430	Add 10	+8	Posterior column	–	
10	310	Add 18	+16	–	–	not fully thawed
11	310	Add 10	+9	–	Pertrochanteric	not fully thawed
12	310	Add 20	+4	Vertical fracture line posteriorly	–	not fully thawed

compression fracture was produced in one experiment (11) and a vertical fracture line posteriorly in the acetabulum in another (12) There were no other fractures in the acetabulum or pelvis probably owing to a change of the physical properties (e g stiffness of the soft tissues)

Nine fractures were produced in 12 experiments in this preliminary study Three were transverse fractures with only a fracture line through the middle of the acetabulum One was a T-fracture through the anterior and posterior columns Two were anterior fractures one of which was a fracture of the anterior column and the other only a vertical fracture-line anteriorly Three were fractures posteriorly in 2 of which the posterior column was fractured In one there was only a fracture line posteriorly The femoral head was not dislocated centrally in any experiment

Conclusion of the preliminary study

This preliminary study gave the conditions necessary for the best position of the specimen to produce an acetabular fracture with the pendulum hitting the trochanter with the hip joint in extension It was found necessary to strike the femoral neck in an axial direction to avoid pertrochanteric and femoral neck fractures The femur had in these 12 preliminary experiments been fixed with silk sutures in the soft tissues in experiments 1 – 8 been transfixed by a Kirschner wire in experiment 9 and been half thawed in experiments 10 – 12 To obtain a better centering of the femoral head and also a stabilization of the femur in the further experiments strings were threaded through canals drilled in the femur and the iliac wing and through the obturator foramen in directions corresponding to normal muscles

Experimental series

Experiments with the femur in extension

Special set up was done according to the conclusions in the preliminary study The pelvis was upside down and the *femur extended The femoral shaft was stabilized to the pelvis* The pendulum hit the trochanter before the lowest point of its course

Results (Table 38)

The first 4 experiments (13 – 16) in this series were carried out with lower energy than previously, as in the preliminary study the best position of the specimen had been determined *and it was thought that maximum force would be concentrated to the acetabulum without* much being lost in the femoral neck or other tissues In one experiment (13) a transverse fracture was produced through both columns In the other 3 no fracture was obtained

Table 38 Experimental acetabular fractures – Hip in extension

		Position of femur		Result		
Experiment	Energy (Nm)	Abduction (Abd) or Adduction (Add) degrees	Rotation degrees	Type of fracture	Femoral neck or pertrochanteric fracture	Remarks
13	325	± 0	– 4	Transverse	–	
14	258	Add 15	– 12☆	–	–	
15	258	Abd 2	+ 35☆☆	–	–	
16	258	Add 5	+ 15	–	–	
17	480	Add 18	+ 10	Transverse	–	
18	480	± 0	+ 38☆☆	Anterior column	–	
19	480	Add 18	± 0	Transverse	–	
20	480	Add 18	– 10☆	Transverse	–	
21	480	Add 14	+ 13	Transverse	–	
22	480	Add 10	+ 18	Vertical fracture line posteriorly	–	osteoarthrosis
23	480	Add 15	– 16☆	Transverse	–	
24	480	Add 7	– 7☆	Transverse	–	
25	480	Add 7	+ 28	Transverse	–	
26	480	Add 2	+ 12	Transverse	–	
27	480	± 0	– 2	Transverse	–	
28	480	± 0	+ 12	Transverse		
29	480	Add 7	– 8☆	–		
30	480	± 0	– 6☆	Anterior column	–	☆☆☆
31	480	Add 10	+ 18	–	–	☆☆☆
32	480	Add 10	– 4☆	Anterior column	–	☆☆☆

☆ = Femur maximal internal rotated ☆☆ = Femur maximal external rotated ☆☆☆ = symphysis and sacrum independently fixed

The energy was then increased to 480 Nm in experiments 17 – 29 In all of these the blow was ideal (with the force along the femoral neck) with the degree of rotation varying from maximal external to maximal internal In 10 experiments transverse fractures were obtained in one an anterior column fracture and in one a vertical fracture-line posteriorly In one experiment (29) no fracture was produced despite ideal position A possible explanation is that the pelvis was from a strong individual (Table 36) and the energy used was not enough to create a fracture A summary of experiments 17 – 29 is given in Table 39 in which it is demonstrated that the degree of rotation has not influenced the localization of the fracture The degree of adduction in these experiments varied between 0 – 18°

Ten transverse fractures were produced in experiments 17 – 29 In 8 of these both columns w r fractured with a displacement between the a etabular fragments of 1 – 1.5 centim ters In 2 experiments there was only a horizontal fracture line through the acetabulum In one experiment there wa an anterior olumn fracture and in one a vertical fracture line posteriorly

In experiments 1 – 29 a central dislocation of the femoral head occurred only once This was interpreted as a result of both the symphysis and the sacrum being stably fixed in the epoxy resin without possibility of individual movement In experiments 30 – 44 these structures were fixed separately offering the possibility to move in the sagittal plane In 3 experiments (30 – 32) with unchanged energy and blow on the extended hip joint the degree of rotation was varied *from maximal internal* (–6) to external rotation (+18) *Two anterior column fractures were produced without dislocation of the femoral head* (30 and 32) and one extra articular fracture through the ramus superior ossis pubis (31)

Comment In the experiments with the femur in extension this was maximal internally rotated in 7 The measured angles between the femoral neck axis and the frontal plane varied between –4 to –16° Three transverse fractures and 2 fractures of the anterior column were produced In 2 experiments the femur was maximal externally rotated and this resulted in a fracture through the anterior column in one experiment

A study was made to obtain an idea of the rotation in the hip joint with the *femur in extension* Both hips in 3 complete pelvic specimens were radiologically *examined with the femur in maximal external and internal rotation respectively* The combined external and internal rotation in the 6 hips varied between 20 – 40 Maximal internal rotation varied from +15 to –15 and maximal external rotation from +20 to 44°

Table 39 Position (rotation) of the femur in 13 experiments (17–29) and type of acetabular fracture

Rotation degree	Transverse	Anterior	Posterior	No fracture	Total
+ 38 → + 10	5	1	1	-	7
0 → 16	5			1	6
Total	10	1	1	1	13

Experiments with the femur in flexion

On the extended hip joint no difficulties had been encountered in producing transverse or anterior fractures irrespective of the degree of rotation To try to produce posterior column fractures experiments were carried out on flexed hip joint In these the degree of abduction and adduction was varied By adduction of the femur we wanted to concentrate the energy to the posterior column

Table 40 Experimental acetabular fractures – Hip in flexion

		Position of femur			Result		
Experiment	Energy (Nm)	Abduction (Abd) or Adduction (Add) degrees	Rotation degrees	Flexion degrees	Type of fracture	Femoral neck or pertrochanteric fracture	Remarks
33	480	Abd 10	+16	90	–	–	Prelim experim
34	480	±0	+13	85	–	–	Prelim experim.
35	480	±0	+10	90	Transverse	–	
36	480	Add 25	+40☆☆	85	–		
37	480	Add 23	+20	90	–		
38	480	Abd 10	–10	90	Transverse	–	
39	480	Abd 16	☆☆☆	60	T–fracture	–	
40	480	Add 40	☆☆☆	70	–	Pertrochanteric	
41	480	Abd 25	☆☆☆	70	Transverse	–	
42	480	Add 30	☆☆☆	75	–	–	
43	480	Abd 30	+10	85	Transverse	–	
44	480	Abd 28	☆☆☆	75	–	–	

☆ = Femur maximal internal rotated ☆☆ = Femur maximal external rotated ☆☆☆ = Measurements on radiographs were *not possible depending* on the degree of flexion (The femur was put in neutral position in experiments 39 40 and 44 and external rotated in experiments 41 and 42)

Results (Table 40)

After 2 preliminary experiments (33 and 34) ideal experimental conditions were obtained With the hip joint flexed 60 – 90° a blow could be directed with almost optimal force con centration along the femoral neck axis

Ten experiments (35 – 44) were carried out In 4 of these with the femur in 23 – 40° ad duction no acetabular fracture was produced In one experiment with the femur in neutral position a transverse fracture was produced In 5 experiments with abduction 10 – 30° a transverse fracture was produced in 3 and a T fracture in one (Table 41)

Of 5 fractures produced in this series 4 were transverse and one a T fracture The transverse fractures were all fractures through both the posterior and anterior columns In 2 the femoral head was dislocated centrally 3 – 4 centimeters and in one of them the superior dome was fractured In 2 the femoral head was not dislocated and in one of them the superior dome was fractured In one experiment a T-fracture through both columns was produced The femoral head was not dislocated and the superior dome was intact

Table 41 Position (abduction – adduction) of the femur in 10 experiments (35 – 44) and type of acetabular fracture

Position of femur Abduction/adduction degrees	Transverse	Anterior	Posterior	No fracture	Total
Adduction 23 – 40	–	–	–	4	4
± 0	1	–	–	–	1
Abduction 10 – 30	4☆	–	–	1	5
	5			5	10

☆ = T fracture in one experiment

Experiments with the femur in flexion

On the extended hip joint no difficulties had been encountered in producing transverse or anterior fractures irrespective of the degree of rotation To try to produce posterior column fractures experiments were carried out on flexed hip joint In these the degree of abduction and adduction was varied By adduction of the femur we wanted to concentrate the energy to the posterior column

Table 40 Experimental acetabular fractures – Hip in flexion

		Position of femur			Result		
Experiment	Energy (Nm)	Abduction (Abd) or Adduction (Add) degrees	Rotation degrees	Flexion degrees	Type of fracture	Femoral neck or pertrochanteric fracture	Remarks
33	480	Abd 10	+16	90	–	–	Prelim experim
34	480	±0	+13	85	–	–	Prelim experim
35	480	±0	+10	90	Transverse	–	
36	480	Add 25	+40☆☆	85	–		
37	480	Add 23	+20	90	–		
38	480	Abd 10	−10	90	Transverse	–	
39	480	Abd 16	☆☆☆	60	T-fracture	–	
40	480	Add 40	☆☆☆	70	–	Pertrochanteric	
41	480	Abd 25	☆☆☆	70	Transverse	–	
42	480	Add 30	☆☆☆	75	–	–	
43	480	Abd 30	+10	85	Transverse	–	
44	480	Abd 28	☆☆☆	75	–	–	

☆ = Femur maximal internal rotated ☆☆ = Femur maximal external rotated ☆☆☆ = Measurements on radiographs were not possible depending on the degree of flexion (The femur was put in neutral position in experiments 39 40 and 44 and external rotated in experiments 41 and 42)


A


B


C


D

Fig 39 Experiment 17 Transverse fracture A *AP view* B *Alar view which clearly demonstrates the fracture through the posterior column* C *External and* D *Internal aspect of the specimen Arrows indicate the fracture*



A



B

Fig 37 Experiment 18 Fracture of the anterior column A External and B Internal aspect of the specimen Arrows indicate the fracture through the anterior column



A



B

Fig 38 Experiment 20 Transverse fractures have separated a fragment that includes part of the weight bearing surface the superior dome A External and B Internal aspect of the specimen Arrows indicate the loose fragment



A



B



C



D

Fig 39 Experiment 17 Transverse fracture A AP view B Alar view which clearly demonstrates the fracture through the posterior column C External and D Internal aspect of the specimen Arrows indicate the fracture



A



B



C

Fig 40 Experiment 26 Transverse fracture A AP view B Foramen obturator view and C Alar view which demonstrate the fracture through the anterior and posterior columns D External and E Internal aspect of the specimen Arrows indicate the fracture


D


E



A



B



C

Fig 40 Experiment 26 Transverse fracture A AP view B Foramen obturator view and C Alar view which demonstrate the fracture through the anterior and posterior columns D External and E Internal aspect of the specimen Arrows indicate the fracture


A


B


C


D

Fig 42 Experiment 35 Transverse fracture with central dislocation of the femoral head The superior dome is intact A AP view B Alar view C Internal aspect of the specimen Arrows indicate the displaced medial wall. D External aspect demonstrating the fracture The superior dome is intact


A


B


C


D

Fig 41 Experiment 27 Transverse fracture through the middle of the acetabulum A *AP view* B *Alar view which demonstrates the fracture through the posterior column* C *External and* D *Internal view of the specimen Arrow points at the femoral head*

During this experimental investigation it was noticed that it was difficult to detect fractures with no displacement between the acetabular fragments at the radiologic examination When the joint was opened at the dissection the fractures were obvious It was also noticed that oblique projections were necessary to determine the fracture-lines

CONCLUSIONS

The following conclusions of the experiments can be made

1 It is possible to produce central acetabular fractures by an impact to the trochanteric region
2 It is important to hit the trochanter so that the force is transmitted axially through the femoral neck and to stabilize the femoral shaft in order to concentrate the energy and to avoid pertrochanteric or femoral neck fractures
3 The degree of rotation of the femur with this in extension does not seem to influence on the type of acetabular fracture produced
4 An energy of 430 Nm was sufficient to produce acetabular fractures

Various types of acetabular fractures (anterior column transverse and posterior column) are calculated to arise when the trochanteric region is hit by a force with the femur in extension and varying degree of rotation, or when the force is applied along the axis of the femur with the hip joint in flexion and varying degree of abduction or adduction (Cauchoix & Truchet 1951 Judet et al 1964, Judet & Letournel 1974) With this concept of the fracture mechanism as a background we have tried to produce experimental acetabular fractures of various types One problem has been to find an optimal experimental set up The difficulties to produce other unusual fractures experimentally have learned us the necessity to concentrate the energy to the actual bone and to avoid non axial energy transmission in the bones that are supposed to act as impact bodies (Peterson et al 1976) To determine the pendulum hit point and the degree of rotation and abduction or adduction of the femur in the experiments it was necessary to x ray the specimen set up before each experiment Adjustments could then be made

After a preliminary study the optimal experimental set up could be defined The difficulties to achieve this even under controlled laboratory conditions may explain the rareness of the acetabular fracture clinically as compared to the frequent occurrence of pertrochanteric and femoral neck fractures and fractures through the pelvic rami as the result of a trauma to the trochanteric region

In the first 29 experiments only one central dislocation of the femoral head was achieved This was interpreted as a possible result of both the symphysis and the sacrum being stably fixed in the same epoxy resin In the following experiments these structures were fixed separately offered the possibility to move in the sagittal plane In 7 acetabular fractures 2 resulted in a severe central dislocation of the femoral head

Only a few isolated posterior column fractures could be produced although the force was transmitted through the femoral neck in maximal internal rotation in several experiments It was noticed that the possible maximal internal rotation that could be performed in the specimen hip joints was far from that calculated necessary for producing these fractures

Different amount of energy was used to find the lowest necessary to produce these fractures The preliminary study showed that all 7 experiments with 430 Nm resulted in acetabular fractures Out of 9 (in all series) with lower energy only 3 resulted in acetabular fractures Fourteen of 16 experiments with 480 Nm resulted in acetabular fractures on an extended hip joint In the experiments with the hip joint in flexion the same energy was used in all This seemed to be sufficient to produce transverse fractures with the femur in abduction or neutral position but insufficient in the 4 experiments with the femur in adduction The posterior column seemed to withstand this energy It is possible that the posterior column fractures are a result of a blow to the knee with the femur in abduction and flexion It is also possible that the energy used in this series was too low Waller (1955) used an energy of 1200 Nm in producing posterior acetabular fractures on flexed hip Creyssel & Schnepp (1961) used 500 Nm on producing central acetabular fractures on whole cadavers

During this experimental investigation it was noticed that it was difficult to detect fractures with no displacement between the acetabular fragments at the radiologic examination When the joint was opened at the dissection the fractures were obvious It was also noticed that oblique projections were necessary to determine the fracture-lines

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The following conclusions of the experiments can be made

1 It is possible to produce central acetabular fractures by an impact to the trochanteric region
2 It is important to hit the trochanter so that the force is transmitted axially through the femoral neck and to stabilize the femoral shaft in order to concentrate the energy and to avoid pertrochanteric or femoral neck fractures
3 The degree of rotation of the femur with this in extension does not seem to influence on the type of acetabular fracture produced
4 An energy of 430 Nm was sufficient to produce acetabular fractures

SUMMARY

Part one

There are discrepancies in reported series regarding treatment and late results of fractures of the acetabulum The purpose of this investigation has been to perform a study of these fractures with reference to frequency, classification, radiologic appearance cause of injury, associated injuries treatment and late results

I During 1963 1973 123 patients with 124 acetabular fractures were admitted to the Departments of Orthopaedic Surgery at Sahlgren Hospital in Goteborg The study has included central acetabular fractures with and without central dislocation of the femoral head and posterior acetabular fractures with or without posterior dislocation of the femoral head Of the 124 acetabular fractures 85 were central and 39 posterior

Central acetabular fractures were classified depending on the degree of central dislocation of the femoral head and the involvement of the weightbearing area i e whether the superior dome was fractured or not

Posterior acetabular fractures were classified depending on the degree of displacement and comminution of the posterior acetabular rim (Waller 1955)

Of 85 patients with *central acetabular fractures* 80 were treated conservatively with immobilization in bed only or with traction through the tibial tuberosity, in some cases in combination with lateral traction through the proximal femur Five patients were treated surgically

Of 39 patients with *posterior acetabular fractures* 19 were treated conservatively with immobilization in bed only or with traction through the tibial tuberosity Twenty patients were treated surgically with open reduction of the acetabular fragment and osteosynthesis

II Onehundred patients with 101 fractures were followed up clinically after 1 1/2 12 years with a mean time for follow up of 6 1 years

Central fractures

The follow up comprised 66 patients with central acetabular fractures 61 of these were treated conservatively 5 surgically

Conservative treatment Results were excellent or good in 75 per cent of the 61 patients conservatively treated Thirty patients without central dislocation of the femoral head had excellent or good results in 90 per cent

Fifteen patients with central dislocation of the femoral head without fracture of the superior dome had excellent or good results in 87 per cent

Sixteen patients with central dislocation of the femoral head with fracture of the superior dome had excellent or good results in 38 per cent

Surgical treatment Five patients were treated surgically and one patient had good result and 4 fair

Posterior fractures

Thirty five patients with posterior acetabular fractures were followed up 17 were treated conservatively and 18 surgically

Conservative treatment The fracture was classified as Type I in 3 patients as Type II in 5 patients and as Type III in 9 patients The results were excellent or good in 82 per cent (Type I 100 per cent Type II 100 per cent Type III 67 per cent)

Surgical treatment The fracture was classified as Type II in 10 patients and as Type III in 8 patients The results were excellent or good in 67 per cent (Type II 70 per cent Type III 63 per cent)

Sciatic nerve injury

Weakness of the foot extensors was registered in 8 patients Seven of these had a posterior acetabular fracture in combination with a posterior dislocation of the femoral head One patient had a central acetabular fracture without central dislocation of the femoral head At follow up the paresis remained in 5 patients

III Ninety-three patients with 94 acetabular fractures were followed up radiologically (61 patients with central acetabular fractures and 33 with posterior acetabular fractures)

Osteoarthrosis was found in 23 of 61 patients with central acetabular fractures (38 per cent) and in 14 of 33 patients with posterior acetabular fractures (42 per cent)

Avascular necrosis of the femoral head was found in 8 patients 5 with central acetabular fractures and 3 with posterior acetabular fractures

Ectopic ossification was noticed in 13 of 99 patients (13 per cent) who were examined radiologically for more than 1 year

Part two

Based on the reports of previous experimental work and on the theories of fracture mechanism in central acetabular fractures an experimental study of these fractures has been performed The purpose was to design an experimental model by which central acetabular fractures could be produced on cadaver pelves and to determine the conditions (position of hip joint, and energy) under which various types of central acetabular fractures could be produced

A preliminary study comprising 12 experiments was performed which gave the optimal specimen set up

Two experimental series one with the femur in extension (20 experiments) and one with the femur in flexion (12 experiments) were then performed In these two series 20 acetabular fractures were produced

We found it important to hit the trochanter so the force was transmitted directly through the femoral neck and to stabilize the femur in order to avoid pertrochanteric or femoral neck fractures The degree of rotation of the femur with this in extension did not seem to influence on the type of fracture produced When a force was applied to the trochanteric region with the femur in flexion and abduction an energy of 480 Nm was sufficient to produce transverse fractures

With the same energy applied to the trochanteric region with the femur in flexion and abduction we did not obtain acetabular fractures, probably owing to insufficient energy

In a total of 44 experiments 29 acetabular fractures of various types could be produced

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REFERENCES

ADAMS, J C (1972) *Outline of fractures* C Livingstone Edinburgh & London.

AHLBÄCK, S O (1971) *Klassifikation av höftledsartros* Nord Med. 85 157

ALLGÖWER M (1966) Luxationsfrakturen im Hüftbereich. Langenbecks Arch. klin. Chir 316 439

ANDERSSON, G (1972) Hip assessment A comparison of nine different methods. J Bone Jt Surg 54-B 621

ARMSTRONG, J R. (1948) Traumatic dislocation of the hip joint. Review of one hundred and one dislocation J Bone Jt Surg 30-B 430

AUSTIN, R T (1971) Hip function after central fracture-dislocation a long term review Injury 3 114

BACKMAN, S (1957) The proximal end of the femur Thesis Acta radiol. Suppl. 146

BARNES S N & STEWART M J (1976) Central fractures of the acetabulum. A critical analysis and review of literature Clin Orthop 114 276

BATRA H C (1976) Central fractures of the acetabulum. Injury 7 171

BOYD, J D Le GROS CLARK Sir W E., HAMILTON, W.J , YOFFEY J.M., ZUCKERMAN Sir S & APPLETON A.B (1958) Textbook of human anatomy 1st ed reprinted. Ed Hamilton W.J p 87 Macmillan and Co Ltd , London

BRAV E A (1962) Traumatic dislocation of the hip Army experience and results over a twelve year period J Bone Jt Surg 44-A 1115

BÖHLER J (1966) Luxationsfrakturen im Hüftbereich Langenbecks Arch. klin Chir 316 417

BÖHLER L (1954) Die Technik der Knochenbruchbehandlung. 12 13 Auflage 2 Band 1 Teil Verlag W Maudrich Wien

CALLISEN H (1778) Quoted by Schroeder 1909

CAMPBELL W C (1936) Posterior dislocation of the hip with fracture of the acetabulum. J Bone Jt Surg 18 842

CARNESALE P G STEWART M.J & BARNES S N (1975) Acetabular disruption and central fracture-dislocation of the hip J Bone Jt Surg 57-A 1054

CAUCHOIX J & TRUCHET P (1951) Les fractures articulaires de la hanche Rev Chir orthop 37 266

CHARNLEY, J (1972) The long term results of low friction arthroplasty of the hip performed as a primary intervention J Bone Jt Surg 54-B 61

COOPER, A P (1824) Treatise on dislocations and on fractures of the joints Churchill, London

COTTALORDA J (1922) Les fractures par enfoncement de la cavité cotyloide These Faculté de médicin de Montpellier

COVENTRY, M B (1974) The treatment of fracture-dislocation of the hip by total hip arthroplasty J Bone Jt Surg 56-A 1128

CREYSSEL J & SCHNEPP J (1961) Fractures transcotyloidiennes du bassin Masson et Cie Éditeurs Paris
DANIELSSON L.G (1964) Incidence and prognosis of coxarthrosis Thesis Acta orthop scand Suppl 66
D AUBIGNÉ M (1968) Management of acetabular fractures in multiple trauma J Trauma 8 333
D'AUBIGNÉ M & POSTEL M (1954) Functional results of hip arthroplasty with acrylic prosthesis J Bone Jt Surg 36–A 451
ECKE H BABAYAN R. BURRI C ENZENROSS H G JUNGBLUTH K.H KRAUS I PANNIKE A RUTER R RUF N TSCHERNE H WEISS H. & WELLER S (1975) *Behandlungsergebnisse der Pfannenosteosyntese* Mschr Unfallheilk Beihefte 124 90
EDEIKEN J & HODES P.J (1973) Roentgen diagnosis of diseases of bone Vol II 2nd Ed Williams & Wilkings Company Baltimore
EICHENHOLTZ S.N & STARK R.M (1964) Central acetabular fractures A review of thirty five cases J Bone Jt Surg 46–A 695
ELLIOTT R.B (1956) Central fractures of the acetabulum Clin Orthop 7 189
ENDER J (1975) Einleitungsvortrag mit Ergebnissen der in den AUKH Österreichs in den Jahren 1967 – 1972 behandelten Acetabulum Frakturen Mschr Unfallheilk Beihefte 124 33
EPSTEIN H C (1961) Posterior fracture-dislocations of the hip Comparison of open and closed methods of treatment in certain types J Bone Jt Surg 43–A 1079
EPSTEIN H C (1974) Posterior fracture-dislocations of the hip Long term follow up J Bone Jt Surg 56–A 1103
FUNSTEN R KINSER P & FRANKEL C (1938) Dash-board dislocation of the hip A report of twenty cases of traumatic dislocation J Bone Jt Surg 20 124
GELEHRTER G (1969) Behandlungstechnik der frischen Huftverrenkungsbruche Chir Praxis 13 113
GÖTHLIN G HINDMARSH J (1970) Central dislocation of the hip The prognosis with conservative management Acta orthop scand 41 476
HUITTINEN V M & SLÄTIS P (1972) Fractures of the pelvis Acta chir scand 138 563
JAHNA H (1975) Ursachen von Misserfolgen nach konservativer Behandlung bei zentralen Huftgelenksverrenkungsbruchen Mschr Unfallheilk Beihefte 124 57
JOHANSSON H & OLERUD S (1971) Acetabularfrakturens operativa behandling Svensk Lak Tidn 68 2023
JUDET R JUDET J & LETOURNEL E (1964) Fractures of the acetabulum classification and surgical approaches for open reduction J Bone Jt Surg 46–A 1615
JUDET R & LETOURNEL E. (1974) Les fractures du cotyle Masson & Cie Éditeurs Paris
KNIGHT R A & SMITH H (1958) Central fractures of the acetabulum J Bone Jt Surg 40–A 1

REFERENCES

ADAMS, J C (1972) Outline of fractures C Livingstone Edinburgh & London

AHLBACK, S O (1971) Klassifikation av hoftledsartros Nord Med 85 157

ALLGÖWER M (1966) Luxationsfrakturen im Huftbereich Langenbecks *Arch Klin Chir* 316 439

ANDERSSON, G (1972) Hip assessment A comparison of nine different methods J Bone Jt Surg 54–B 621

ARMSTRONG, J R (1948) Traumatic dislocation of the hip joint Review of one hundred *and one dislocations J Bone Jt Surg 30–B 430*

AUSTIN R T (1971) Hip function after central fracture-dislocation a long term review Injury 3 114

BACKMAN S (1957) The proximal end of the femur Thesis Acta radiol Suppl 146

BARNES S N & STEWART, M J (1976) Central fractures of the acetabulum A critical analysis and review of literature Clin Orthop 114 276

BATRA H C (1976) Central fractures of the acetabulum Injury 7 171

BOYD J D Le GROS CLARK Sir W E HAMILTON W J YOFFEY J M ZUCKERMAN, Sir S & APPLETON A B (1958) Textbook *of human anatomy* 1st ed *reprinted* Ed Hamilton W J p 87 Macmillan and Co Ltd , London

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BÖHLER J (1966) Luxationsfrakturen im Huftbereich Langenbecks Arch Klin Chir 316 417

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COOPER A P (1824) Treatise on dislocations and on fractures of the joints Churchill London

COTTALORDA J (1922) Les fractures par enfoncement de la cavité colyloide These Faculté de médicin de Montpellier

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CREYSSEI J & SCHNEPP J (1961) Fractures transcotyloidiennes du bassin Masson et Cie Editeurs Paris
DANIELSSON L.G (1964) Incidence and prognosis of coxarthrosis Thesis Acta orthop scand Suppl 66
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D AUBIGNÉ M & POSTEL M (1954) Functional results of hip arthroplasty with acrylic prosthesis J Bone Jt Surg 36–A 451
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GÖTHLIN G HINDMARSH J (1970) Central dislocation of the hip The prognosis with conservative management Acta orthop scand 41 476
HUITTINEN V M & SLÄTIS P (1972) Fractures of the pelvis Acta chir scand 138 563
JAHNA H (1975) Ursa hen von Misserfolgen nach konservativer Behandlung bei zentralen Huftgelenksverrenkungsbruchen Mschr Unfallheilk Beihefte 124 57
JOHANSSON H & OLERUD S (1971) Acetabularfrakturens operativa behandling Svensk Lak Tidn 68 2023
JUDET R JUDET J & LETOURNEL E (1964) Fractures of the acetabulum classification and surgical approaches for open reduction J Bone Jt Surg 46–A 1615
JUDET R & LETOURNEL E (1974) Les fractures du cotyle Masson & Cie Éditeurs Paris
KNIGHT R A & SMITH H (1958) Central fractures of the acetabulum. J Bone Jt Surg 40–A 1

REFERENCES

ADAMS, J C (1972) Outline of fractures C Livingstone, Edinburgh & London

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ALLGÖWER M (1966) Luxationsfrakturen im Huftbereich Langenbecks Arch klin Chir 316 439

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COOPER A P (1824) Treatise on dislocations and on fractures of the joints Churchill, London

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D AUBIGNÉ M (1968) Management of acetabular fractures in multiple trauma *J Trauma* 8 333
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ECKE H BABAYAN R BURRI C ENZENROSS H G JUNGBLUTH K H KRAUS I PANNIKE A RUTER R RUF N TSCHERNE H WEISS H & WELLER S (1975) Behandlungsergebnisse der Pfannenosteosyntese Mschr Unfallheilk *Beihefte* 124 90
EDEIKEN J & HODES P J (1973) Roentgen diagnosis of diseases of bone Vol II 2nd Ed Williams & Wilkings Company Baltimore
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ELLIOTT R B (1956) *Central fractures of the acetabulum.* Clin Orthop 7 189
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EPSTEIN H C (1961) Posterior fracture-dislocations of the hip Comparison of open and *closed methods of treatment in certain types* J Bone Jt Surg 43–A 1079
EPSTEIN H C (1974) Posterior fracture-dislocations of the hip Long term follow up J Bone Jt Surg 56–A 1103
FUNSTEN R KINSER P & FRANKEL C (1938) Dash-board dislocation of the hip A *report of twenty cases of traumatic dislocation J Bone Jt Surg* 20 124
GELEHRTER G (1969) Behandlungstechnik der frischen Huftverrenkungsbruche Chir Praxis 13 113
GÖTHLIN G HINDMARSH J (1970) Central dislocation of the hip The prognosis with conservative management Acta orthop scand 41 476
HUITTINEN V M & SLÄTIS P (1972) Fractures *of the pelvis Acta chir* scand 138 ta 563
JAHNA H (1975) Ursachen von Misserfolgen nach konservativer Behandlung bei zentralen Huftgelenksverrenkungsbruchen Mschr Unfallheilk Beihefte 124 57
JOHANSSON H & OLERUD S (1971) Acetabularfrakturens operativa behandling Svensk Lak Tidn 68 2023
JUDET R JUDET J & LETOURNEL E (1964) Fractures of the acetabulum classification and surgical approaches for open reduction J Bone Jt Surg 46–A 1615
JUDET R & LETOURNEL E (1974) Les fractures du cotyle Masson & Cie Éditeurs Paris
KNIGHT R A & SMITH H (1958) Central fractures of the acetabulum J Bone Jt Surg 40–A 1

LEHTONEN, R (1968) *A study of traumatic dislocations of the hip joint and fractures of the acetabulum* Thesis Ann Chir Gynaec Fenn 57 Suppl 163

LETOURNEL E (1966) Traitement des fractures de *cotyle* Dixieme congres international de chirurgie et de traumatologie Paris *sept 1966*

LETOURNEL, E (1966) Die operative Versorgung der Huftgelenkpfannenbruche *Langen* becks Arch Klin Chir 316 422

LEVINE, M A (1943) A treatment of central fractures of the acetabulum A case report J Bone Jt Surg 25 902

LIDSTRÖM, A (1961) En variant av trokanterstrack Nord Med 66 1679

LIPSCOMB, P R (1961) *Fracture-dislocation of the hip Amer acad of orthop surg In* structional course lecture 18 102

MALGAIGNE J F (1855) Traité des fractures et des luxations Tome II Des luxations J B Bailliere Paris

NERUBAY J GLANCZ, G & KATZNELSON A (1973) Fractures of the acetabulum J Trauma 13 1050

NICOLL E A (1966) Treatment of acetabular fractures Dixieme Congres international de chirurgie et de traumatologie Paris sept 1966

PALEARI G L & GUALTIERI G (1971) The operative treatment of fractures of the ace tabulum Lo Scalpello 1 27

PARÉ A (1575) Quoted by Nicoll (1966)

PEARSON J R & HARGADON EJ (1962) Fractures of the pelvis involving the floor of the acetabulum J Bone Jt Surg 44–B 550

PETERSON L ROMANUS B & DAHLBERG E (1976) Fracture of the *collum tali – an experimental study J Biomechanics* 9 277

PORTER M F (1973) Operative treatment of acetabular fractures Proc roy Soc Med 66 632

RENNÉ J & SCHMELZEISEN H (1975) Die Behandlung der zentralen Huftgelenksluxation unter Verwendung der Trochanterzugschraube Mschr Unfallheilk Beihefte 124 240

ROMANI A *(1928) Le fratture per affondamento traumatico della cavita cotiloide con* lussazione intrapelvica della testa femorale La Chirurgica degli organi de movimento Vol XII Fasc 4 360

ROWE C R & LOWELL J D (1961) Prognosis of fractures of the acetabulum J Bone Jt Surg 43–A 30

RYDELL N W (1966) Forces acting on the femoral head prosthesis Thesis Acta orthop *scand Suppl 88*

SCHROEDER W E (1909) Fracture of the acetabulum with displacement of the femoral head into the pelvic cavity *Quarterly bullentin of the Northwestern University medical* school Vol *II (1909/10)* pp 9-42

SOLHEIM K & SKREDE O (1973) Acetabular fractures Acta orthop scand 44 728

STEWART, M J & MILFORD L W (1954) Fracture-dislocation of the hip An end result study J Bone Jt Surg 36–A 315

STEWART MJ McCAROLL H R & MULHOLLAN J S (1975) Fracture-dislocation of the hip Acta orthop scand 46 507

THEVENOT L (1904) Recherches expérimentales sur les fractures limitées du fond de la cavité cotyloide Rev de Chir 29 253

THOMPSON V P & EPSTEIN H C (1951) Traumatic dislocations of the hip A survey of two hundred and four cases covering a period of twenty-one years J Bon Jt Surg 33-A 746

TILLMANS H (1905) Quoted by Lehtonen 1968

TIPTON W D AMBROSIA R D & RYLE G P (1975) Non-operative management of central fracture-dislocations of the hip J Bone Jt Surg 57-A 888

TROJAN E (1975) Die operative Behandlung der Huftverrenkungsbruche Mschr Unfall heilk Beihefte 124 65

TROJAN E & PERSCHL A (1956) Die Behandlungsergebnisse von 79 frischen traumatischen Huftgelenksverrenkungen und *Huftgelenksverrenkungsbruchen Ergebn Chir* Orthop 40 90

URIST M R (1947) Injuries to the hip joint Traumatic dislocations incurred chiefly in jeep accidents in World War II Amer J Surg 74 586

URIST M R (1948) Fractures of the acetabulum The nature of the traumatic lesions treatment and two year end results Ann Surg 127 1150

URIST M R (1949) *Fracture-dislocation of the hip joint* The nature of the traumatic lesion treatment late complications and end results J Bone Jt Surg 30-A 699

WALLER A (1955) Dorsal acetabular fractures of the hip (Dashboard fractures) Thesis Acta chir scand Suppl 205

VAUGHN G T (1912) Quoted by Barnes S N & Stewart M J 1976

WECHSELBERGER F (1956) Erfahrungen und Behandlungsergebnisse an 57 frischen Huftpfannenbruchen mit zentraler Luxation des Oberschenkelkopfes Ergebn Chir Orthop 40 224

VECSEI V (1975) *Zur operativen Versorgen der Huftverrenkungsbruche* Arch orthop Unfall-Chir 82 107

WESTERBORN A (1928) Beitrage zur Kenntnis der Beckenbruche und Beckenluxationen Thesis Acta chir scand Suppl 8

WESTERBORN A (1954) Central dislocation of the femoral head treated with mold arthroplasty *J Bone Jt Surg 36-A 307*

WILENIUS R (1943) Über Beckenbruche Thesis Acta chir scand Suppl 79

VIRVEAUX (1899) *Des enfoncements traumatiques de la cavité cotyloide These Faculté* de médicine et de pharmacie de Lyon

VOLLMAR J & WACHTLER St (1956) Zur Kenntnis und Therapie der *Huftpfannenverletzungen* Langenbecks Arch klin Chir 283 208

ZEUMER G (1966) Zur Behandlung und Prognose der Azetabulumfraktur Zbl *Chir* 91 126

LEHTONEN R (1968) *A study of* traumatic dislocations of the hip joint and fractures of the acetabulum Thesis *Ann Chir Gynaec Fenn 57 Suppl 163*
LETOURNEL E (1966) *Traitement des fractures de cotyle* Dixieme congres international de chirurgie et de traumatologie Paris sept 1966
LETOURNEL E (1966) Die operative Versorgung der Huftgelenkpfannenbruche Langenbecks Arch klin Chir 316 422
LEVINE M A (1943) *A treatment of central fractures of the acetabulum* A case report J Bone Jt Surg 25 902
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LIPSCOMB P R (1961) Fracture-dislocation of the hip Amer acad of orthop surg Instructional course lecture 18 102
MALGAIGNE, J F (1855) Traité des fractures et des luxations *Tome II Des luxations* J B Bailliere Paris
NERUBAY J GLANCZ, G & KATZNELSON A (1973) Fractures of the acetabulum J Trauma 13 1050
NICOLL E A (1966) Treatment of acetabular fractures Dixieme Congres international de chirurgie et de traumatologie Paris, sept 1966
PALEARI, G L & GUALTIERI G (1971) The operative treatment of fractures of the acetabulum Lo Scalpello 1 27
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From the Department of Orthopaedic Surgery University of Hong Kong Hong Kong
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To my father and mother
John and Mollie O Brien
Sydney Australia

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None of this work would have been possible without the loyal cooperation and expert nursing care of the Matron Sister Barbara and the staff there

My apprenticeship in spinal surgery was patiently directed by Professor Arthur Yau whose particular skill with severe neglected kyphosis has made possible excellent results

Dr Louis Hsu has been a loyal support for seven years and together we have shared the satisfactions and the trials of our work Sister Gabriel Sister Aquinas and Dr Donald Yue have provided the medical care these patients needed with good humoured understanding of our surgical bias

In the engineering work, Dr J Clark and Mr L Yesterton of the Department of Mechanical Engineering Hong Kong University have spent many hours on the problems of design of the apparatus and in the development of the force measuring system

On my sabbatical leave in the Departments of Orthopaedic Surgery I and Medical Electronics in Goteborg Sweden I greatly appreciated the help and insight I was given into the fields of medical electronics and biomechanics In particular I would like to thank Professor Henry Wallman of the Laboratory of Medical Electronics and Dr Lars Sonnerup of the Department of Mechanical Engineering Chalmers University of Technology Dr Kerstin Bostrom was most helpful in the autopsy studies connected with Part IV of the thesis

PART I

THE HALO PELVIC APPARATUS

PREFACE

The rapid development of the halo-pelvic technique was made possible in Hong Kong by the large number of children with gross spinal disorders for whom some successful method of treatment had to be found

Our experiences with these children over the last five years form the principal part of this study In order to be comprehensive a basic introduction to the apparatus and to the safest procedure for application is outlined in Part I

In Part II the clinical material methods of treatment and results are the evidence of our work and a measure of its success The complications encountered are described in Chapter II of this section For the sake of example and clarity they are dealt with in some detail

Part III describes a combined project when intravital wireless telemetry was used to measure the forces being transmitted through the spine and provided confirmation of several of the virtues of the apparatus which beforehand we had only been able to assume

The anatomical studies in Part IV establish the fundamental safety of the preferred landmarks for applying the halo and the hoop to the patient along with some basic studies of the growth and mechanical strength of the bony ilium

As this paper specifically studies the halo pelvic apparatus details such as surgical approaches to the spine respiratory function studies and complications related to surgery have been mentioned only briefly so as not to blur the relevancy of the text

THE HISTORY OF THE DEVELOPMENT OF HALO PELVIC TRACTION

The concept of halo pelvic traction is attributed to Dr William Green of Boston U S A (24) thus it is a little surprising that its clinical development has been so recent In the fifties the skull halo had been developed and perfected by Perry and Nickel (50) who then proceeded to develop a form of pelvic fixation

In 1958 in Hong Kong Hodgson and Yau used a form of halo pelvic traction for a patient with tuberculous kyphosis Six threaded pins were inserted into the anterior and posterior superior spines of the ilium and the region of the tubercle of each crest thus employing the skull halo principle

The first attempts at pelvic fixation by Perry and coworkers at Rancho Los Amigos California involved the use of the skull halo technique directly on the pelvis (51) This produced too much skin tenting around the pins resulting in skin necrosis and the need for early removal of the apparatus Secondly they tried using coarsely threaded pins angled directly down the long axis of each of the four superior spines but in this instance the cancellous bone held less than three weeks Part of the problem was that severely paralysed patients had very thin iliac crests which were unable to hold the pins

Garrett (51) used the button wire technique placing the buttons on the inside of the pelvis and bringing the wires out on to the pelvic hoop This worked very well for approximately ten weeks until irritation began and the fixation had to be removed Nelson (42) whilst working at Rancho Los Amigos developed a three pin unit which could be attached directly to the iliac crests The patient tolerated this quite well although its fixation to the pelvis required considerable surgery and there was some drainage in each case

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threaded pelvic pins which transfixed the iliac crests They described their experience with their first four patients in 1970 (10)

Our clincal experience began in January 1969, the apparatus and the method of fitting it to the patient have been modified and altered in various ways for reasons of safety but the basic technique has remained the same

THE APPARATUS

The halo-pelvic apparatus consists of five basic parts (Figs 2 3 and 4)

a) The skull halo
b) The pelvic hoop and pins and their attachments
c) Four extension bars connecting the hoop to the halo
d) The force measuring system a spring at the base of each of the four extension bars
e) The back winder (Fig 4)

a) Originally a Rancho type halo was used the design was simplified to facilitate manufacture and to reduce the weight of the halo This meant elimination of the posterior upward flare (as fusion proximally to the skull has not been necessary in our patients) and of the bushings for locking the halo pins in place Instead the pins were locked in position by a nut on the threaded pin external to the skull halo Multiple threaded holes were added around the perimeter allowing a wide selection of pin sites

b) The pelvic hoop and pins initially resembled those described by DeWald and Ray (10) with four female attachments clamped to a hoop of rectangular cross section which accommodated the exten sion bars (Fig 1) The pelvic pins were held in position on the hoop by four clamps

c) The extension bars were fixed proximally by socket head cap screws to the skull halo The bars were threaded over their distal ten to fifteen centimetres and effective lengthening of the distance

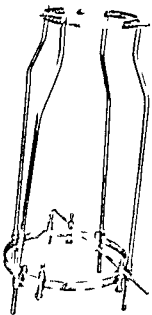


Figure 1 The Mark I halo pelvic apparatus

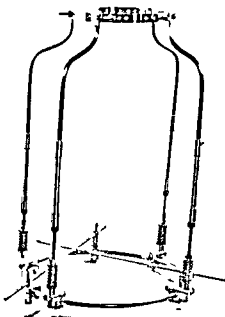


Figure 2 The Mark II halo pelvic apparatus Note the multiple holes around circumference of the skull halo for alternative sites for placing the skull pins

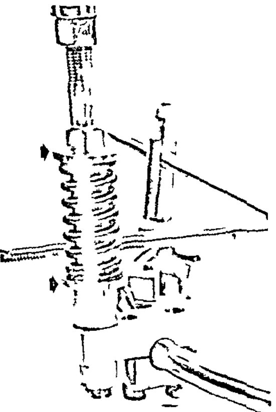


Figure 3 A detailed photograph of a compression spring at the base of an extension bar for measuring the forces The distance between the arrows is mea ured with a vernier caliper

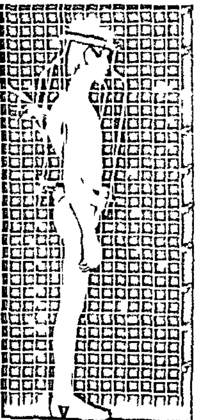


Figure 4 Lateral photograph of case 49 a twelve-year old patient with severe paralytic scoliosis A back winder is attached to the two posterior extension bars (arrow)

between the halo ard hoop was achieved by winding the nut above the female attachment down the thread on the extension bar (one millimetre thread)

Two difficulties arose with this Mark I design (Fig 1) Firstly the extension bars protruding distally beyond the pelvic hoop made sitting difficult for the patient as the two anterior extension bars abutted against the thighs Secondly patients with pelvic obliquity presented particular difficulty with the fitting of he extension bars because of the rectangular cross sectional shape of the pelvic hoop

Mod f cations to the original design have been made to obviate the problem of the extension bars protruding beyond the pelvic hoop (Fig 2)(5) A threaded leeve is now used instead of the original extension bar which means that none of the extension bar extend beyond the hoop The pelvic hoop has been de igned so hat it is now round in cross section making adjustment of the extension bars an easy matter even when pelvic obliquity is extreme (Fig 3)

d) In October 1970 a force measuring system was designed to record the forces being applied to the spine (5) The four springs sit in sleeves at the base of the extension bars and they are gradually compressed as the distraction progresses (Fig 3) Each spring has a stiffness of approximately 300 pounds per inch (5 4 kp/mm) The amount of spring deformation measured can be converted into a measurement of force from a standard table thus providing a valuable guide line in managing the patients during distraction

e) An adjustable teel pressure pad which clamps to the posterior e tension bars can be gradually applied again t a kyphos or rib hump providing an additional local corrective force Initial orrection of a severe spinal curve is obtained by lengthening the spine but in the latter stages of correction a direct force a plied at the apex of the deformity is d sirable (Fig 13 b) Two points should be remembered if the back winder is u ed Fi stly a thi k foam r er disc must be interpo ed betw een the steel pad ar e skin as there is a high ri k of pre ure

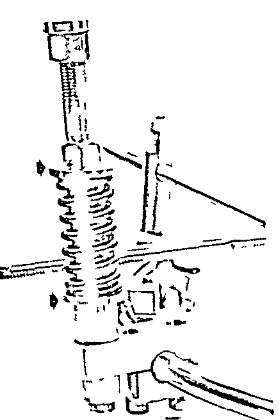


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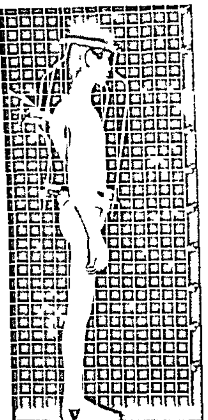


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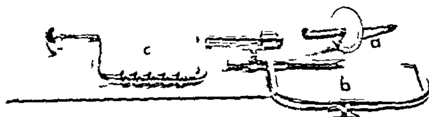


Figure 5 A photograph of the basic instruments required

a) The torque screw driver

b) The drilling jig

c) The carpenter's brace

recrosis, particularly when an anterior oblique and a posterior vertical skin incision have been used in approaching the spine With this combination of incisions a large area of skin is rendered anaesthetic, and there is a high risk of developing ischaemic skin lesions by using the back winder Secondly, it must be removed from the posterior extension bars when force measurements are being taken

FITTING OF THE HALO PELVIC APPARATUS

In the early months of experience with the halo-pelvic apparatus it was apparent that a drilling jig was essential for accurate insertion of the pelvic pins in order to avoid the severe complications surrounding an inaccurate placement A drilling jig for arthrodesis of the hip (3) was easily modified for this purpose (Fig 5)

Major difficulties with several patients were encountered when the extension bars were applied at the same time as the skull halo, pelvic pins and hoop As a result the fitting of the apparatus now entails two stages firstly, the skull halo, pelvic pins and hoop are fitted under general anaesthesia, secondly, several days later the extension bars are applied to the pelvic hoop and skull halo with the patient awake and cooperating

General anaesthesia is required, although the skull halo itself can be fitted under local anaesthesia The patient s tolerance of this first anaesthesia is a fair indication of his ability to withstand subsequent anaesthesia for spinal operations Endo-tracheal anaesthesia is desirable because of the repeated alterations in position of the patient on the operating table

Perry has stressed that the skull halo must be placed below the greatest transverse diameter of the skull (52) The assistant may hold the patient's neck with the head extending beyond the end of the operating table but if the halo is to be used with any regularity it is best to have a small thin metal extension to the table on which the patient s occiput can rest (44) The anterior pins are placed in the shallow fossae above the outer aspects of the eyebrows

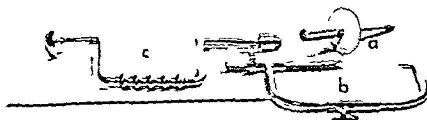


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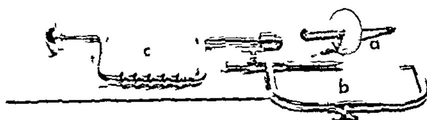


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The outer table of the skull is quite thick and with the shouldering of the pins a secure purchase is obtained without excessive and dangerou penetration

The posterior points selected are above and approximately two centimetres behind the ear Several of the skull halos slipped off after distraction had commenced and therefore it was felt that the use of supplementary skull pins would be advisable, particularly for the heavier and the long term patients If six pins are to be used, the extra two pins are placed approximately two centimetres behind the posterior ones (see Part IV)

The sterile skull halo is placed in position on the patient s scalp resting on his forehead and the ideal holes in the halo are chosen for inserting the skull pins The pins are then tightened, making sure that the skull is in the centre of the halo when the pins are in the outer table of the skull, diametrically opposite pins should be tightened at the same time to ensure this After the pins have been tightened by finger pressure a torque screw driver (Figs 5 and 6a) is then used and the pins are driven into the outer table with a torque force of 5 5 pound inches (0 06 kpm) This procedure is completed by applying the outer locking nuts carefully to the outer extension of the skull pins so that when the nuts are tightened the skull pin is not advanced any further This can be done by locking the pins with the screw driver

The patient s position i now changed he is moved down onto the middle of the table and placed in the lateral position where the upward facing hemi pelvi is prepared and draped (Fig 6b) This position is chosen for several reasons Firstly it is easy to see the appropriate landmarks Secondly the drilling jig is easily applied to the iliac cre t with the patient in the lateral position A false sense of security should not exist at this stage as the viscera do not fall away from the upper iliac crest There i a negative intraperitoneal pressure which prevents any gross movement of the peritoneal contents within the peritoneal cavity

The points for applying the drilling jig are now selected The anterior point for introducing the pin is on the iliac crest

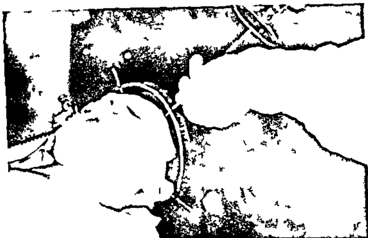


Figure 6 a Fitting of the skull halo

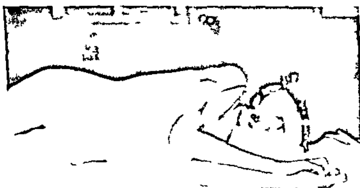


Figure 6 b The patient placed in the lateral position for insertion of the pelvic pins

Figure 6 a) (b) (c) (d) and (e) A series of photographs to demonstrate the method of fitting of the halo pelvic apparatus

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Figu e 6 e Fitting of the extension bars with the patient awake and with the halo suspended by a spring balance

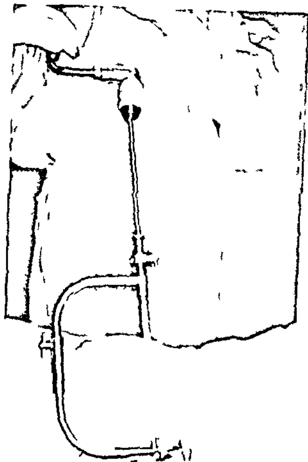


Figure 6 c The drilling jig in position and the pelvic pin in erted with a carpenter s brace

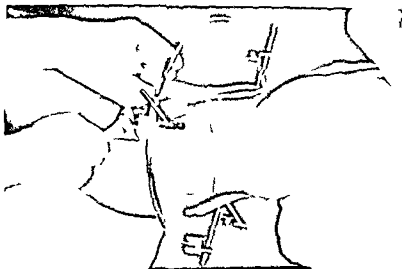


Figure 6 d The pelvic hoop being placed on the pelvic pins at the end of the operating table

continued ur il an equal lergth of pin i protruding anteriorly and posteriorly

It is important that the pin is felt to engage in the anterior part of the crest as it is very easy particularly in thinner patients for the pin to slide down the outer or the inner tables of the crest Should this happen the eating of the jig must be checked and a further incision attempted The pin in the middle of its course through the crest migh be slightly within the pelvis (and it may be palpated here with the patient under anaesthesia)

One must beware of the peritoneum becoming wrapped around the pin at this time this will be apparent as the anterior abdominal wall becomes sucked into the iliac fossa It is essential should this happen that the insertion be stopped and a second point chosen on the iliac crest for applying the pin

There will be no difficulties encountered at thi stage with patients who have a normally developed pelvis However in the much younger patients and those with wasting of the pelvis associated with long standing paralysis and pelvic obliquity the insertion of the pins may present problems If any difficulties are met or any anxiety felt about the precise placement of the pin it is advisable to make a small incision just above the middle of the iliac crest and to place an exploratory finger within the iliac fo sa o that the direction of the pin should it be intrapelvic may be felt with accuracy and the viscera pushed aside

It is important to note that the point of pin entry is not at the anterior spine but at some distance from it and it is best before applying the halo pelvic apparatus to any patient for the surgeon to examine a bony pelvis and check the relative positions of the land mark recommended When a line is drawn connecting the anterior with the posterior superior spines a pin crossing this gap will be almost totally within the iliac fossa with a great danger of bowel perfora tion

When the first pin has been placed in position the skin wounds are utured loosely around it small dry dressings are applied to these

opposite the gluteal tubercle, the tubercle of the crest which may be as much as five centimetres upwards and posterior from the anterior superior iliac spine (Part IV, Fig 42) It is readily palpated as the subcutaneous iliac crest is widest at this point With this particular part of the crest grasped between the thumb and index finger a transverse incision is made down to the bone, or cartilage cap of the crest the length and depth of the incision depends on the amount of subcutaneous fat present

The selected point of emergence is the posterior superior iliac spine, which is subcutaneous and easily identified by the overlying skin dimple and a stab incision is made just medial to it

The drilling jig is now applied connecting these two landmarks It is important to have the points on the jig quite sharp so that they will penetrate the bony landmarks the telescopic section of the jig ensures that one can use a good deal of hand pressure to push the points securely into bone then the telescopic portion of the jig is tightened Ideally an assistant steadies the U part of the jig whilst the pin is being inserted

For insertion of the pin, a carpenter s brace is used (Fig 6c) Power driven machinery for this purpose would be dangerous for if any part of the pin is within the iliac fossa it is likely to wrap the peritoneum around itself Apart from this it is likely that with high speed drilling a good deal of bone necrosis occurs (33) and this will merely increase the amount of discharge and probable infection around the pelvic pins

Preliminary tapping of the sharp drilling point of the pelvic pin through the cortex, or the cartilage cap of the crest of the ilium is advisable and the first few turns of the pin through the bone may be made with a Steinman pin holder Thereafter the carpenter s brace is attached to the end of the pin and with slow rotation the pin is advanced through the crest

Its emergence will be heard and felt by the pin rubbing against the sharp posterior part of the drilling jig At this point the jig is detached from the crest the brace is reattached and the pin s route

complications For these reasons it is wise to maintain the patient on clo e observation for 24 hours after fitting of the halo and th pelvic hoop

FITTING OF THE EXTENSION BARS

The fitting of the extension bars can take place when the patient has fully recovered from he general anaesthesia and the urgical pro edure The patient is seated comfortably on a stool beneath a strong spring balance which is suspended from the ceiling (Fig be) The balance has attached to it a serie of thin rope and hooks which are hooked into four free holes of the full halo A pulley system permit he patient to be drawn up and this force is registered on the spring balance The patient should be suspended by the maximum amount of forc which i tolerable comfortable and not producing neck pain This is often 25 per cent of the patient s body weight but will obviously depend on many factors particularly the thickne s and strength of the patient s neck

With the patient in this semi suspended position the four extension bars are affixed to the skull halo by the socket head cap screws and to the pelvic hoop by the special clamp attachments If force mea uring spring are used they must be checked for stiffness before being placed in position All the fittings are tightened and the pulley with the spring balance can then be released

Distra ion can commence several days after the fitting of the bar provided that preliminary osteotomies are not required

DAY TO DAY MANAGEMENT OF THE PATIENT

The skull halo pins require little attention but they should be inspected each day and any discharge should be removed and cultured All skull pins are checked one week after fitting and tightened up again with the torque screw driver to 5 5 pound inches (0 06 kpm) If a patient experiences pain it is due to looseness and the skull pin should be tightered should it be a sociated with excessive

wounds, and the patient s position changed to the opposite lateral position on the table which ideally is broken across its middle thus allowing for the protrusion of the first pin

The patient may therefore need to be steadied by the assistant whilst the second pin is being inserted in an identical manner to the first

In those patients with pelvic obliquity the pelvis on the higher side often has better muscles attached to it and for this reason it is better developed but its abnormal position increases the risk of perforation of the bowel

The patient's position is again changed to the supine position the lower half of his body being supported by the assistant whilst the pelvic hoop is run over the lower limbs and with the appropriate fittings, locked to the pelvic pins (Fig od) Whether the pelvic hoop be placed above or below the pins depends largely on how distally the spinal surgery will extend If fusion be it anterior or posterior is to include the lower lumbar spine then it is advisable to place the pelvic hoop below the pelvic pins It is important for the locking attachments to be firmly tightened so that there is no movement of the pins as this might produce pain and promote infection

POST OPERATIVE MANAGEMENT

During post operative management the patient is best nursed on a split mattress so that the posterior part of the pelvic hoop is accommodated within the split and does not cause excessive pressure of the pelvic pins against the iliac crest

The skull halo pins may cause some headache which should be easily managed with salicylates Any excessive pain associated with the skull halo pins implies looseness of the fixation

Likewise excessive pain associated with the pelvic pins may indicate their inaccurate insertion or looseness which will produce pain in the iliac crests Excessive and continuing pain may denote bleeding or an injury to the intestines this will be discussed under

complications For these reasons, it is wise to maintain the patient on close observation for 24 hours after fitting of the halo and the pelvic hoop

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The patient may therefore need to be steadied by the assistant whilst the second pin is being inserted in an identical manner to the first

In those patients with pelvic obliquity, the pelvis on the higher side often has better muscles attached to it and for this reason it is better developed but its abnormal position increases the risk of perforation of the bowel

The patient s position is again changed to the supine position, the lower half of his body being supported by the assistant whilst the pelvic hoop is run over the lower limbs and with the appropriate fittings locked to the pelvic pins (Fig 6d) Whether the pelvic hoop be placed above or below the pins depends largely on how distally the spinal surgery will extend If fusion be it anterior or posterior is to include the lower lumbar spine then it is advisable to place the pelvic hoop below the pelvic pins It is important for the locking attachments to be firmly tightened so that there is no movement of the pins as this might produce pain and promote infection

POST-OPERATIVE MANAGEMENT

During post-operative management the patient is best nursed on a split mattress so that the posterior part of the pelvic hoop is accommodated within the split and does not cause excessive pressure of the pelvic pins against the iliac crest

The skull halo pins may cause some headache which should be easily managed with salicylates Any excessive pain associated with the skull halo pins implies looseness of the fixation

Likewise excessive pain associated with the pelvic pins may indicate their inaccurate insertion or looseness which will produce pain in the iliac crests Excessive and continuing pain may denote bleeding or an injury to the intestines this will be discussed under

a) Myelography is essential to exclude any intraspinal lesion not ete table with normal routine radiography or to define the extent of an internal kypho is with cord compre sion If there is a lesion present in the spinal canal u h as diastematomyelia or an intra thecal lipoma then a trong corrective force applied to the spine is very likely to produce a paraplegia

b) Respiratory function tests are essential and are used routinely They should always be mandatory in the operative treatment of scolio sis especially in evere paralytic curves There is the po sibility of a tracti n injury to the vagus nerve which will produce loss of the cough impulse and sputum retention The sequelae of such a complication would be difficult to assess if base line respiratory studies had not been done

Incorrect fitting of the apparatus

The patient should be relatively comfortable after the fitting of the halo and the hoop and if there is any undue pain it suggests that there is something wrong If the skull halo ha been firmly fixed then there hould be no more than discomfort associated with the skull pins if they have been placed in the proper position One cause of intense pain has been placing one of the anterior pins too medially near or through a supraorbital nerve

Familiarity with the proper siting for placement of the skull pins i mportant One must bear in mind the anatomy of the cutaneous nerves of the calp in the region of the eyebrows and he ears as their irritation with a skull pin produces intense pain

Patients with meningomyelocele may have had a Spitz Holter valve in position usually above and behind one ear If the halo is to be used the pins on the same side as the valve must be placed at some distance from it and its catheter so as to avoid problems

The pelvic pins if firmly embedded in the iliac crests and locked tightly to the pelvic hoop should not cause anything more than disco fort If there is pain about the site of entry or exit of one

discharge then that pin should be changed The multiple holes in the skull halo permit these changes of pin without any difficulty

The pelvic pin sites likewise are examined daily and kept covered with small dry dressings any discharge should be cultured and the appropriate antibiotic used

As regards keeping the patients in bed, it has been customary to confine them to bed only when they are recovering from surgery or are suffering from excessive pain and/or discharge from their pelvic pin sites

The most important single factor in avoiding infection associated with the skull and pelvic pins is that they must have rigid fixation in bone Whilst they are firmly fixed in bone there is only a very slight likelihood of infection Once looseness develops infection becomes almost an automatic sequela

PITFALLS AND GUIDELINES IN USING THE HALO PELVIC APPARATUS

Selection of the patient

Halo-pelvic traction should be reserved for those patients whose spinal deformities cannot be well corrected by other methods of treatment currently available In Hong Kong, the main indications for the use of the technique have been tuberculou kyphosis (40) and paralytic scoliosis (30%) After more than five years experience with halo pelvic traction the indications have altered a little but precise indications cannot yet be categorically stated For those patients with severe scoliosis and severe respiratory insufficiency and those with kyphotic deformities, the halo-pelvic apparatus has in our hands remained the mainstay of management

Faulty preparation of the patient

Any patient whose deformity is evere enough to require treatment with the halo pelvic apparatus should have

a) myelography before surgery and
b) adequate preliminary respiratory function test

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of the pelvic pins then a check should be made to see that skin is not excessively tented about a pin This can present problems, as an area of necrotic skin will develop with sloughing and inevitable infection

In the first 24 hour-period after the fitting of the halo and the pelvic hoop the patient should be kept under routine observation and if there are any difficulties such as rising pulse, increasing temperature, or abdominal pain then a general surgeon should be consulted, particularly if there is any possibility of one of the pins being intrapelvic

The importance of accurate placement of the pelvic pins cannot be over-emphasised To the author s knowledge there have been four instances of damage to the peritoneum or the intestines with incorrect insertion of the pelvic pins Our experience with laceration of the peritoneum is referred to later (Part II Chapter II) Three instances occurring in other clinics included a) injury to the outer layer of sigmoid colon detected post mortem in a patient who died from other causes after surgery b) perforation of the sigmoid colon and c) one patient who sustained perforation of both the sigmoid colon and the caecum with the two pins

This particular sequence has been developed because of its safety for the patient Points to be re-emphasised are

1) A drilling jig must be used for safe accurate insertion of the pelvic pins

2) A power drill is contraindicated for this procedure It is dangerous and likely to produce a potentially fatal bowel injury A carpenter s brace is recommended as it is simple afe and if used slowly is least likely to cause bone necrosis

3) The lateral position of the patient is selected because it is the easiest po ition in which to apply the drilling jig to see all the bony landmarks at one time and for the surgeon to position himself when doing the instrumentation

4) The extension bars are not put on the patient while he is under anaesthesia It is preferable and advisable to apply them several days later

Complications likely to occur during distraction of the patient

The most common faults are acute distraction of the cervical spine and cranial nerve injuries To avoid these problems there are four basic guide lines which must be used during distraction They are

A) Regular clinical observation

B) Daily neurological assessment

C) Regular lateral radiographs of the cervical spine

D) The use of force measurements

A Regular clinical observation

Any complaint which the patient makes during distraction must be dealt with immediately In this respect the nursing and paramedical staff must be given encouragement and responsibility in the manage ment of these patients It is wise to include them in the general teaching programme so that they are familiar with the apparatus and its use and know how to release the tension in the extension bars should the patient complain of pain or disability The most common complaint during distraction is of neck pain and one must not continue distraction until this has settled If neck pain persists then the extension bars should be shortened by several turns until the patient is comfortable again

Nursing care includes daily inspection of the skull halo and the pelvic pin sites and any change in their state discharge pain or looseness must be reported to the surgeon in charge

B Neurological assessment

A daily neurological assessment of each patient must be made during active distraction For this purpose a basic chart (Table 1) has been developed which permits a rapid check of the nerves at risk

If a nerve injury occurs or if the patient notices some weakness the extension bars must be shortened immediately as the time for recovery of the nerve injury which is usually a neurapraxia will depend on how long the nerve has been over stretched The quicker the tension is released the faster will be the return of nerve function

TABLE 1

BASIC NEUROLOGICAL EXAMINATION FOR PATIENTS UNDERGOING DISTRACTION

A Spinal cord

Questions

1) Any weakness in the legs?
2) Any numbness in the legs?
3) Any loss of bladder function?

Tests

1) Up or down going toes?
2) Any clonus of ankles or knees?

B Cranial nerves (Tests for VI, IX, X XII)

Questions

1) Any double vision?
2) Any difficulty swallowing?
3) Difficulty coughing?
4) Any change in voice?
5) Any tongue weakness?

Tests

1) Eye movements (VI)
2) Palate reflex (IX)
3) Explosive cough (X)
4) Quality of speech nasal? (IX or X)
5) Extend tongue is it midline? (XII)

C Upper limbs

Questions

1) Difficulty in moving hand arm or shoulder joint?
2) Any numbness or weakness of the hand?

Tests

1) Abduct the shoulder (C5, 6)
2) Flex the forearm (C5 6)
3) Test grip of hand
4) Test sensation of finger tips (C6-T1)

C Lateral radiographs of the cervical spine

The upper cervical spine because of its relative frailty is the most susceptible region of the spine to over distraction For this reason regular lateral radiographs of the cervical spine are mandatory They should be taken with the patient at a fixed distance from the x ray plate so that measurements of films will be comparable

D The use of force measurements

The use of a force measuring system is most important It provides an indication of the amount and rate at which the stress on the spine is being built up From studies of the pathological changes in the cervical spine with distraction it is apparent that when forces measuring over 60 per cent of the body weight are applied the complication rate becomes significantly higher (Part II Chapter II) By having force measurements available these complications can be minimised Some patients have flexible curves such as those with long paralytic C curves while others like patients with tuberculous kyphosis have more rigid deformities The rigidity of the curves differs enormously from patient to patient and depends mainly on their etiology The force measurements provide the information necessary to avoid building up dangerously high forces too rapidly and this is most important in the rigid deformities

Removing the halo pelvic apparatus

The actual removal of the apparatus is relatively simple deciding when to remove it may occasionally present problems

The precise procedure will depend on the deformity and the method which has been used to correct and fuse it It will also depend to a large extent on the internal fixation used and its stability The most common deformity will be a scoliosis and the most common instrument the Harrington rod it must be remembered that after several weeks in the halo pelvic apparatus there is quite signi ficant osteoporosis and the Harrington hooks are more likely to cut through the softened bone if the spine is suddenly released It is for this reason that often the extension bars are shortened by 1 or 2 millimetres each day so as to gradually load the rod and place some stress through the fusion mass If there is any slipping of

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Inaccurate timing in the removal of the halo pelvic apparatus

One error is to remove the halo pelvic apparatus too early which may result in a significant loss of some of the correction obtained When internal fixation is possible (usually the Harrington rod) it should be used at the time of posterior fusion and the traction in the halo pelvic apparatus should be maintained for a further four to six weeks The rod can then be gradually loaded by a slight daily shortening of the extension bars as rapid release is likely to produce compression fractures of the osteoporotic posterior elements by the hooks

This phenomenon is of relatively minor importance compared to the great advantages of the apparatus for patients with spinal deformities and respiratory crippling In such cases consideration should be given to internal fixation when appropriate and to the removal of the apparatus when a body jacket could be considered as a reasonable alternative

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The history of the development of the halo pelvic apparatus has been described as has the apparatus together with various modifications and improvements which have been made over the years

A detailed account of the fitting of the halo pelvic apparatus is presented with particular emphasis on several safety factors which include

1) The use of a drilling jig and the anatomical landmarks chosen in the iliac crests

2) Placing the patient in a lateral position on the operating table during insertion of the pelvic pins

3) Fitting the extension bars at a later stage with the patient awake and co o erating

the implants at this stage, it will be noticed by the patient and check radiographs should be done forthwith

When the patient has been in the apparatus for some months large holes will have developed in the crests where the pelvic pins have sawn away the bone with which they are in contact When the extension bars are slackened a little, these are likely to become even more mobile and therefore painful This will often force the surgeon to remove the apparatus a little sooner than he may have anticipated

The actual removal of the apparatus is quite straightforward Under general anaesthesia the extension bars are removed Next the skull pins are removed from the skull and the halo being particularly careful to cover the eyes which are at risk Now the pelvic pins are removed using a carpenter's brace They can be removed either from the front or back, the length of pin which has been protruding is prepared with iodine solution before extracting it from the iliac crest

The opened wounds are covered with small dry dressings and these invariably heal within a week

Should there be some concern about the internal fixation or maintaining the correction that has been achieved with the halo pelvic apparatus, it is possible to apply almost an entire body jacket with the patient still in the halo-pelvic apparatus Proximally the ca t can be moulded up to the manubrium sterni and posteriorly to the base of the neck, this may be extended proximally to include the neck when the apparatus has been removed Distally it can be extended down around the pelvic pins to embrace the pelvis so that the pins can be removed and the pelvic portion of the plaster then completed

Window of an appropriate size may then be removed from the pelvic portion of the body jacket to dress the skin wounds which heal rapidly Attention should be given to the pres ure on anaesthetic skin over the back if an oblique thoracotomy incision has been combined with a midline posterior vertical incision In such cases it is routine to remove that area of plaster which impinges against skin devoid of

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PART II

CLINICAL INFORMATION: TREATMENT RESULTS AND COMPLICATIONS

Pitfalls and guidelines in using the halo-pelvic apparatus are described with emphasis on the correct selection of the patient and with particular attention directed towards avoiding complications during the use of the halo pelvic apparatus

CHAPTER I CLINICAL MATERIAL METHODS OF TREATMENT AND RESULTS

INTRODUCTION

104 consecutive unselected patients with severe spinal deformities have been treated with the halo pelvic apparatus at the Duchess of *Kent Children s Orthopaedic Hospital and Convalescent Home Sandy Bay* Hong Kong *over a 3 5 year period from January 1969 to August 1972*

Age and sex

The average age of the patients was 15 years (range 3 to 26 years) 47 patients (45 per cent) were males Their average age was 14 7 years (range 3 to 23 years) 57 patients (55 per cent) were females Their average age at the beginning of treatment was 15 2 years (range 5 to 26 years)

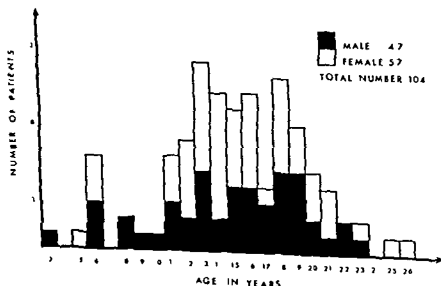


Figure 7 Barograph to show the age and sex of 104 patients

average time is an indication of both the severity and the rigidity of the deformities as well as the associated respiratory insufficiency from which these patients suffer

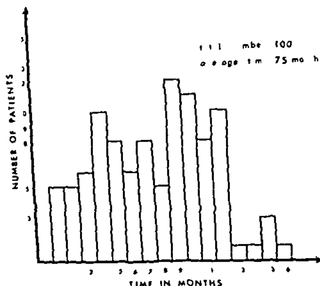


Figure 8 Barograph to demonstrate the length of time patients spent in the halo pelvic apparatus

HALO PELVIC APPARATUS AS EXTERNAL FIXATION OR AS A CORRECTING INSTRUMENT

Whilst most patients had halo pelvic distraction to correct major spinal deformities in some (cases 28 73 89 90 103) the apparatus was used mainly as a means of external spine fixation so as to provide stability in situations where the spine was particularly unstable There were also several patients where maximum distraction was not attempted because of the potential risk to the spinal cord however stability was provided by the apparatus and slight careful distraction was allowed

Etiology of deformity

The etiology of the patients' deformities was

1 Tuberculous kyphosis There were 42 patients with tuberculous kyphotic deformities (40 per cent) of which 25 were males and 17 were females Their average age at the commencement of treatment was 16 1 years (range 3 to 26 years)

2 Paralytic scoliosis 31 patients had severe paralytic scoliosis (30 per cent) 15 were males 16 were females and the average age was 14 1 years (range 6 to 25 years)

3 Idiopathic scoliosis 15 patients (14 per cent) had severe idiopathic scoliosis There were 14 females and 1 male patient and their average age was 15 6 years (range 6 to 21 years)

4 Congenital kyphoscoliosis 10 patients with congenital kyphoscoliosis (10 per cent) included 4 males and 6 females Their average age at the beginning of treatment was 12 8 years (range 6 to 19 years)

5 Neurofibromatosis kyphoscoliosis 6 patients had deformities due to neurofibromatosis (6 per cent) 2 males and 4 females and their average age was 13 8 years (range 10 to 19 years)

6 Salvage group A separate study was made of the 8 scoliosis patients (paralytic - 4 patients idiopathic 4 patients) with previous posterior spinal fusion requiring osteotomies before correction and revision of the fusion

There were four deaths during treatment (cases 40 41 42, 96) Three were patients with severe tuberculous kyphosis and one had a severe congenital scoliosis Each of these patients died shortly after major spinal surgery and they will be referred to later All four patients had gross fixed spinal deformities associated with severe respiratory insufficiency

The average time a patient spent in the halo pelvic apparatus was 7 5 months (range 1 to 16 months)(Fig 8) The most common period of time in the apparatus was 9 months (12 patients) This long

Extent and degree of deformity

The average number of vertebrae destroyed by the tuberculous process was 6 (range 3 to 9 vertebrae) (Fig 11)

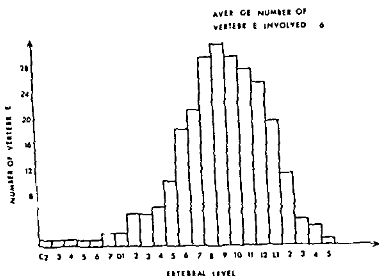


Figure 11 Barograph demonstrating the level and number of vertebrae destroyed by tuberculous disea e process The average number of vertebrae involved per patient was 6

The vertebral body most commonly destroyed was the 9th thoracic vertebra The average angle of kyphosis measured 117 degrees (range 59 to 147 degrees)

Previous surgery

There were 11 patients who had had previous surgery for their tuberculous disease This surgery included fusions in all but two cases where debridements alone were done

Cord compression

16 patients had clinical evidence of cord compression before surgery All had significant narrowing of the spinal canal best demonstrated

Introduction

There were 42 patients with tuberculous kyphosis, three of these patients died during treatment In one of the remaining 39 patients the apparatus was used as external spine fixation rather than as a correcting instrument There were 25 males (average age 16 0 years) and 17 females (average age 16 3 years) (Fig 9) Their average time in the halo-pelvic apparatus was 8 4 months with a range of 1 to 16 months (Fig 10) The average length of follow-up for this group of patients was 2 9 years

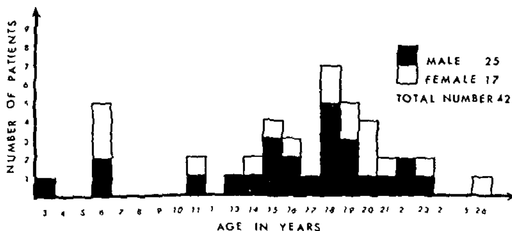


Figure 9 Tuberculous kyphosis Barograph showing the age and sex of patients

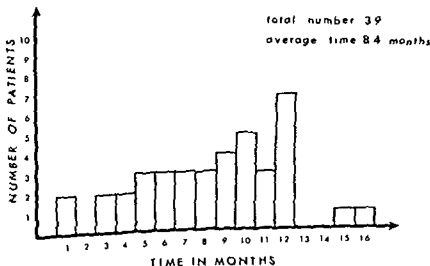


Figure 10 Tuberculous kyphosis Barograph showing the length of time spent in the halo pelvic apparatus

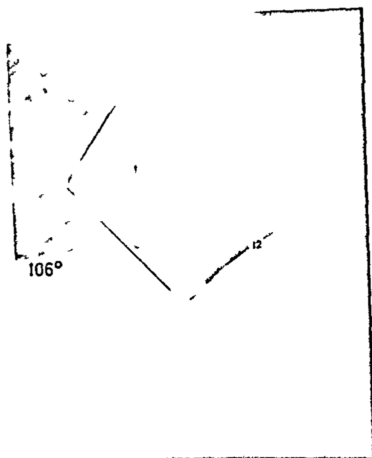


Fig re 12 Case I A lateral myelogram in tuberculou kyphosis to demonstrate the acute angulation of the spinal canal and it narrowing at the level of the internal kyphos This knuckle of bone must be removed before safe distraction can be undertaken

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3) Fitting the extension bars at a later stage with the patient awake and co operating

by myelography (Fig 12)

The degree of cord compression varied clinically from slight spasticity in the lower limbs in most patients to the more extreme variety with marked spasticity severe clonus of knee and ankle and walking being difficult, if not impossible This latter group represents the usual manifestations of penetration of the cord by the tuberculous disease process (28)

METHOD OF TREATMENT

The general plan of treatment in these patients was to decompress the spinal cord by removing the internal kyphos and following gradual correction over some weeks with halo pelvic distraction, to perform anterior and posterior fusions (64)

Chemotherapy

The routine treatment included the standard anti-tuberculous drugs, even for those patients with apparently healed spine disease The drugs were continued for up to 18 months Reactivation of infection in several earlier patients after surgery has now made the inclusion of the appropriate drug therapy routine

Planning the operations

The sequence of operations while conforming to a basic pattern was varied according to the needs of each individual patient This entailed mobilisation of the deformity and simultaneous cord decompression by removing the internal kyphos gradual correction and then fusions This planning depended on the site and extent of the kyphos and the respiratory reserve of the patient

Four separate combinations of mobilising osteotomies and fusions were employed

A One stage osteotomy - Three-quarter circumferential osteotomy

This ent

1 Remo kyphos and half the (usu ntane

fus the same sitting

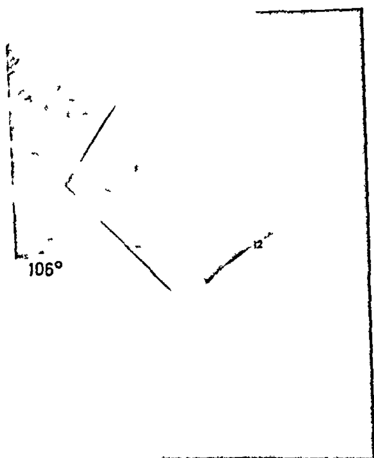


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1 Removal of the internal kyphos and half the (usually) spontaneously fused posterior elements at the same sitting

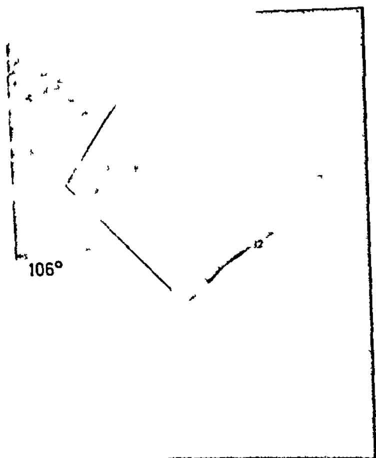


Figure 12 Case 1 A lateral myelogram in tuberculous kyphosis to demonstrate the acute angulation of the spinal canal and its narrowing at the level of the internal kyphos This knuckle of bone must be removed before safe distraction can be undertaken

2 Following maximal distraction posterior fusion

3 Anterior fusion

B Two stage osteotomies

This included

1 Removal of the internal kyphos followed by distraction

2 Posterior osteotomy, after which further distraction

3 Posterior fusion

4 Anterior fusion The biggest single drawback to this sequence is that it involves four major operations

C Combined posterior osteotomies and fusion

This sequence is essentially the same as (B), except that the posterior osteotomies and fusions are included at the one sitting (Figs 13 a b c) The three stages therefore include

1 Removal of the internal kyphos via the usual anterior approach

2 Posterior osteotomies and extensive fusion and when maximal distraction has been achieved,

3 anterior fusion (Fig 13 c)

D Extrapleural costotransversectomy approach

The internal kyphos may be removed from in front of the spinal cord by an extrapleural costotransversectomy approach (5 cases) This must be considered for those patients with severe respiratory insufficiency and kyphoses which are either very deep or else situated in the cervico dorsal spine Because of severe respiratory impairment two of these patients required elective pre-operative tracheostomy

A complete circumferential osteotomy in one operation is not advisable because apart from danger to the cord and its blood supply the subsequent distraction will merely pull the limbs of the kyphos apart without necessarily improving the angle of the deformity A thin bridge of bone must initially connect the limbs of the kyphos so that distraction will hinge the kyphos open

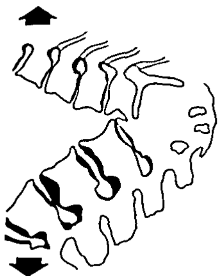


Figure 13 a Pre operative tracing Correction requires forces applied in the direction shown by arrows

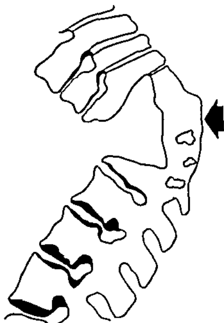


Figure 13 b Tracing towards completion of distraction Corrective force is now applied over the external kyphos (arrow)

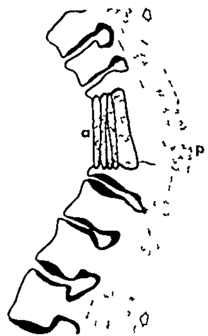


Figure 13 c Tracing after anterior (a) and posterior (p) fusions Note extent of posterior fusions (arrows) and bulk of anterior bone graft

Figure 13 Case 23 Tuberculous kyphosis Tracings of lateral radiographs before during and after surgery
Technique used was method of treatment (c) see text

2 Following maximal distraction posterior fusion

3 Anterior fusion

B Two stage osteotomies

This included

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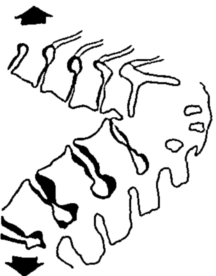


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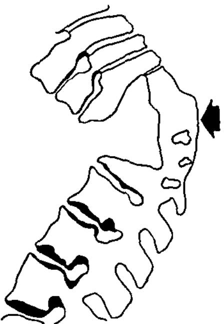


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Figure 13 Case 23 Tuberculous kyphosis Tracings of lateral radiographs before during and after surgery
Technique used was method of treatment (c) see text

2 Following maximal distraction, posterior fusion

3 Anterior fusion

B Two stage osteotomies

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3 Posterior fusion

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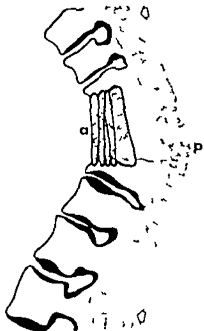


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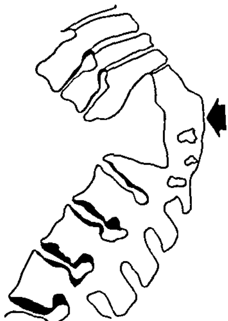


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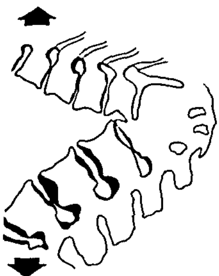


Figure 13 c Tracing after anterior (a) and posterior (p) fusions Note extent of posterior fusions (arrows) and bulk of anterior bone graft

Figure 13 Case 23 Tuberculous kyphosis Tracings of lateral radiographs *before* during and after surgery
Technique used was method of *treatment* (c) see text

No osteotomies were performed in five patients (cases 14, 22 25 30 32), as they had relatively mobile and less marked deformities associated with active disease in the spine (their average age was 7 years) Following very carefully supervised distraction they subsequently had anterior and posterior fusions

A one-staged osteotomy was used in 12 patients and a two-stage osteotomy in 20 patients 6 of these 20 patients had combined posterior osteotomies and fusions Two patients required revision of the osteotomies in order to mobilise the deformities sufficiently for distraction to be effective

Two patients had an anterior spinal fusion alone (cases 3, 6), the remaining patients had anterior and posterior fusions In several cases the latter was done when loss of correction had already occurred In order to maintain the correction achieved, a double fusion is mandatory, especially in those patients with severe deformities

Post operative management

Following the last operation the patients were maintained in the halo pelvic apparatus until the grafts had consolidated Initially this period of time was usually up to 6 months but it has been reduced more recently because of the higher incidence of cervical spine complications associated with prolonged immobilisation Following removal of the halo pelvic apparatus under general anaesthesia the patients remained in bed for one week until the pin site wounds had healed and a full length body cast was applied to provide a total period of immobilisation of twelve months

RESULTS TUBERCULOUS KYPHOSIS (Table 2)

Of the 42 patients 3 died as a result of surgery 2 had the apparatus removed early and in one case it was used as a holding device The remaining 36 patients were followed for an average of 2 9 years (range 1 25 to 4 5 years)

TABLE 2

TUBERCULOUS KYPHOSIS

Case number	Pre op degree (average)	Maximum correction		Follow up	
		Average	as a %	Correction (average)	Length of time in years
1 to 10	117°	to 80° (Corr of 37°)	32	93° (Loss of 13°)	3 9
11 to 20	114°	to 70° (Corr of 44°)	39	77° (Loss of 7°)	3 1
21 to 27	106°	to 73° (Corr of 33°)	32	76° (Loss of 3°)	2 5
31 to 39	128°	to 101° (Corr of 27°)	22	104° (Loss of 3°)	1 7
Total number of patients 36	117°	to 81° (Corr of 36°)	31	88° (Loss of 7°)	2 9

There were no figures to indicate that deformities more proximal in the spine achieved better correction because the variables were so great age activity of disease and previous surgery etc From a mechanical point of view however it is apparent that the more proximal regions in the spine have greater forces applied in the halo pelvic apparatus and the clinical impression is that the younger the patient the more active and the more recent and the more proximal the disease the greater the correction with the halo pelvic apparatus

The average pre operative angle of kyphosis was 117 degrees and after correction and fusion the average angle was 81 degrees representing a correction of 36 degrees (or 31 per cent) As most deformities were in the thoracic spine where the normal kypho is measured from 20 to 40 degrees (54) this correction is in fact better than it would seem from the angular measurement alone At

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follow-up of the 36 patients, three years later, there was an average loss of 7 degrees of correction The final correction was 30 degrees (or 26 per cent)

Various factors were analysed to determine whether they had any significant influence on the final result and the correction achieved The younger patients who had active disease had a significantly better correction Those who had a more extensive mobilising excision of the internal kyphosis likewise had a better correction, as would be expected Surprisingly there was no difference between those patients who had had previous spinal fusions, and those who had no previous surgery

The patients (1) who had had previous fusions and (2) those without previous surgery were analysed separately Those with previous fusion (11 patients) had a pre-operative angle of 116 degrees corrected to 78 degrees (a correction of 38 degrees or 33 per cent) with a loss at follow-up of only 3 degrees

Those who had not had previous surgery (25 patients) had a pre-operative angle of kyphosis of 118 degrees corrected to 84 degrees (a correction of 34 degrees or 29 per cent) At follow up a final correction of 89 degrees or a loss of 5 degrees was measured There was thus no marked difference in the end result whether the patient had had previous fusion or not

The patients were taken in four separate chronological groups (see Table 2) to evaluate whether significant improvement in either the techniques of surgical mobilisation or use of the halo pelvic apparatus had occurred with increasing experience The average pre-operative angle of kyphosis was approximately the same and the degrees of correction were similar in the first three groups However the smaller correction in the fourth group (cases 31 to 39) reflected the greater deformity in those patients who have been treated latterly

Loss of correction after surgery

More than 10 degrees of lo s occurred in 4 patients One expects to lose no more than 5 degree if the basic rules are adhered to and if the bone grafts have been protected for a ufficient period of tire Loss of correction in several of the early patients was due to failure to carry out a routine posterior fusion The average loss of correction was 7 degrees

There was one pseudarthro is in this group probably caused by a posterior fusion too short to protect the vulnerable anterior grafts (case 18)

The average number of anterior spinal grafts u ed was 5 (usually rib struts) but in several of the patients with lumbar lesions blocks of ilia crest were used The average length of the anterior spinal graft as measured on the first post operative radiographs was five centimetres

Minimal loss of correction occurred under the following circumstances
1) where anterior and posterior fusions were done
2) an adequate period of immobilisation in the halo pelvic apparatus
3) where a sufficient volume of autogenous bone graft was used
4) when the posterior fusion ex ended proximally and distally well into the secondary lordotic curves (which were also corrected signi ficantly with distraction)
5) when the sites of the posterior osteotomy were sufficiently covered with bone graft

The following case report is included to demonstrate the principles involved in correcting tuberculous kyphoses A fifteen year old male patient (case 20) had a kyphotic deformity of 121 degrees and clinica signs of spinal cord compression (Fig 14 a) The treatment programme included (1) excision of the entire internal kyphos to decompress the cord and mobilise the deformity (2) gradual distraction (one to two millimetres per day) followed by (3) posterior osteotomies and a fusion Finally rib grafts were placed under compression into the

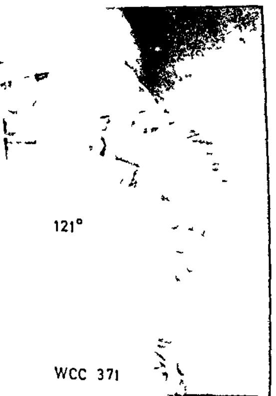


Figure 14 a Lateral radiograph before correction

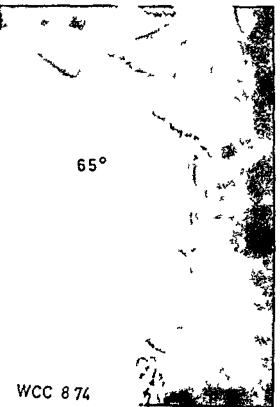


Figure 14 b Lateral radiograph three years and five months after surgery No loss of correction has occurred

Figure 14 (a) and (b) Case 20 *Tuberculous kyphosis in a fifteen year old male patient*

anterior interbody gap At follow up three years and five months later the correction of 65 degrees had been maintained (Fig 14 b)

Neurological and cervical spine complications

16 patients had clinical evidence of marked spinal cord compression before surgery 13 were completely relieved of their spasticity 3 patients were paraplegic aft r surgery (cases 31 34 36) the pre operative clinical condition indicated that they had penetration of the spinal cord by the tuberculous disease process (28) and this was confirmed at the time of posterior surgery in two of the patients where tuberculous follicles were detected on the dura mater

During the course of correction 2 patients developed increased spasticity with the combination of close observation and the ability to release the distraction immediately the tension on the cord was reduced and the spasticity in both patients ubsided

30 patients had cervical spine radiographs available 14 of these patients (47 per cent) developed cervical spine complications as a result of distraction in the halo pelvic apparatus These and the neurolog cal complications mentioned above will be discussed in full detail in the section on complications

SUMMARY AND CONCLUSIONS

4? patients w th tuberculous kyphosis were treated by osteotomies correction with the halo pelvic apparatus and fusions

The average follow up of these patients was 2 9 years (range 1 25 to 4 5 years) The average initial correction of the kyphos was 36 d grees 3 patients died following surgery all of them with severe deformities and respiratory insufficiency

3 patients with penetration of the cord by the disease process and near co plete paraplegia were completely paraplegic after spine surge y

Late neglected kyphotic deformities have asso iated cord compression

and respiratory insufficiency They can only be corrected with any safety by multiple staged operations and with gradual distraction before fusions are done The halo-pelvic apparatus provides the stability necessary for this programme of management and does not interfere with the respiratory impairment from which these patients suffer

2 PARALYTIC SCOLIOSIS

Introduction

31 patients with paralytic scoliosis commenced treatment in the halo-pelvic apparatus There were 15 males (average age 13 0 years) and 16 females (average age 15 1 years)

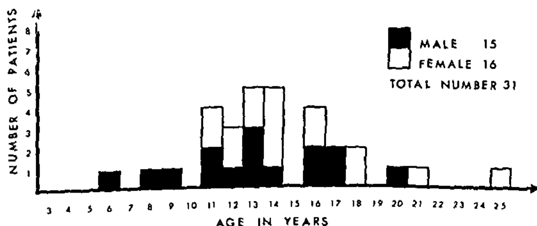


Figure 15 Paralytic scoliosis Barograph demonstrating the age and sex of patients

The average age of the patients was 14 1 years (see Fig 15) Three patients required removal of the apparatus before treatment had been completed (see Complication), four had had previous fusions which required osteotomy before correction they will be discussed eparately (Salvage group)

The average period of time in the apparatus for the paralytic scoliosis patients was 7 6 months (Fig 16)

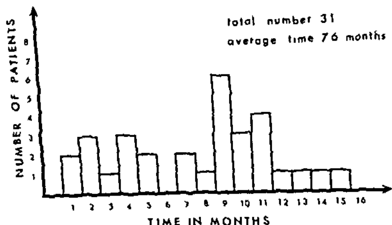


Figure 16 Paralytic scoliosis Barograph to show the time spent in the halo pelvic apparatus The average time was 7 6 months

Site and extent of deformity

The curve types were as follows thoracic 13 patients thoraco lumbar 12 patients lumbar 6 patients The average major curve measured 111 degrees (range 59 to 164 degrees) the average flexibility with suspension was 25 per cent These measurements were made from radiographs taken with the patient suspended from a head halter a posture maintained without discomfort for several seconds

An average number of 9 vertebrae was involved in the major curve (range from 6 to 14 vertebrae) The barograph (Fig 17) confirmed that the most common vertebrae involved were thoracic 10 and 11 with a high incidence of lumbar vertebrae in the major curve

Paralytic pelvic obliquity will be discussed separately as it is felt that this deformity is major enough to warrant separate consideration

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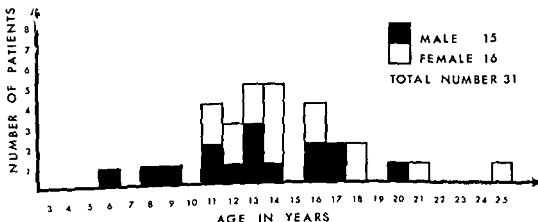


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Other surgery involved

Of the 31 patients with paralytic scoliosis only 8 did not require associated surgery for their limb deformities The majority required extensive surgery for correction of hip and knee contractures the result of long standing poliomyelitis The general aim of the treatment was to make the patient as independent as possible and to allow him to sit or walk with the minimum possible effort required

METHODS OF TREATMENT

The treatment programme (Table 3) included correction with the halo pelvic apparatus followed by

A) posterior fusion without a Harrington rod (11 patients)

B) posterior fusion with a Harrington rod (3 patients)

C) Dwyer s operation and the supplementary posterior fusion without a rod (5 patients)

D) Dwyer s operation and posterior fusion with rodding (3 patients)

E) posterior releases without fusion followed by Dwyer s operation (2 patients)

The 7 patients not accounted for in this treatment summary were as follows

a) three patients had early removal of the halo pelvic apparatus

b) four patients who had osteotomy and correction of previous posterior fusion masses will be considered later together with a similar number of idiopathic cases in the so called salvage group

The patients who had the halo pelvic apparatus removed prematurely had a combined staged anterior (Dwyer) and posterior correction and fusion (2 patients) except for one (aged six years) who has not yet had surgery

A preference for supplementary anterior surgery

With 51 per cent (average) correction of a paralytic scoliosis possible with the halo pelvic apparatus (range 24 to 81 per cent)

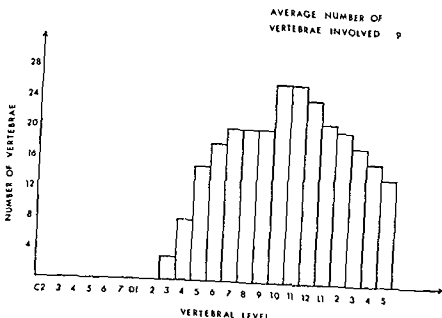


Figure 17 Barograph to demonstrate the vertebrae included in the major curve in paralytic scoliosis

Respiratory insufficiency

Although the association of paralytic spinal deformities with depleted lung function presents one of the major hazards in this field of work (23) this paper will not deal in any detail with the problem of respiratory insufficiency The accurate assessment of lung function before during and after surgery is a vital aspect of the general management of these patients Supportive respiratory therapy before and during surgery the need for tracheostomy assisted respiration after surgery the practicability of an anterior approach and the advisability of staging long spinal fusions are all questions which require to be evaluated in collaboration with a respiratory physician

Severe respiratory insufficiency was most commonly seen in patients whose curves were collapsing or situated in the thoracic spine Whilst post operative respiratory function tests did not always indicate a great improvement in lung function the patients were subjectively much better because they required less effort and energy with sitting or walking, once the spine had been centred and stabilised over the pelvis

and little further correction possible with the Harrington rod the addition of the anterior approach seemed appropriate in many case Further correction with Dwyer s instrumentation should be considered when the patient s type of scoliosis and his re piratory function deem it advisable A posterior fusion with rodding was then done to include the entire deformed spine (+7) Further correction with Harrington s instrumentation was often neither possible because of o te porosis nor was it advisable because of an already taut spinal cord

RESULTS

24 patients with paralytic scoliosis not previously treated had an average pre operative curve of 111 degrees corrected by the halo pelvic apparatus to 55 degrees an average correction of 51 per cent

The average length of follow up was 3 3 years and the average loss of correction was 10 degrees

These patients have been grouped according to the type of surgery which they had undergone (Table 3) Group A (11 patient) had a posterior fusion without rodding Their average pre operative curve was 115 degrees which corrected to 57 degrees with distraction a correction of 51 per cent Their average loss of 16 degrees at the follow up is a reflection of the failure to use internal fixation

Group B (3 patients) had posterior fusions with rodding following maximal correction with the halo pelvic apparatus Their curve averaged 100 degrees and it corrected to 45 degrees with distraction representing a correction of 55 per cent Their loss of correction at follow up was only 6 degrees and the advantage of internal fixation is apparent when compared with Group A

Group C (5 patients) had Dwyer s instrumentation following distrac tion and subsequently a posterior fusion without rodding They had an average cur e of 113 degrees corrected to 54 degrees with distrac- tion an average of 51 per cent correction The Dwyer s operation achieved a total correction of 64 per cent the loss of correction at follow up avera ed only 1 degree

TABLE 3

PARALYTIC SCOLIOSIS - RESULTS

Group	Type of treatment	No of patients	Pre-operative degree	Correction with halo-pelvic apparatus (degrees)	(%)	Correction with Dwyer s instrumentation	Final correction at follow-up (average 3 3 years)(degrees)
A	P S F without Harrington rod	11	115^0	to 57^0	51	-	73^0 (Loss of 16^0)
B	P S F with Harrington rod	3	100^0	to 45^0	55	-	51^0 (Loss of 6^0)
C	Dwyer P S F without Harrington rod	5	113^0	to 54^0	51%	41^0 (64%)	42^0 (Loss of 1^0)
D	Dwyer P S F with Harrington rod	3	110^0	to 56^0	49%	31^0 (72%)	36^0 (Loss of 5^0)
E	Dwyer with posterior osteotomies (no fusion)	2	112^0	to 66^0	41%	57^0 (49%)	74^0 (Loss of 17^0)

patient and a Harrington rod was then in erted to protect the newly-added bone graft (case 64)

One patient in whom a Harrington rod was not u ed developed a p eudarthrosis eighteen months after immobilisation had been discontinued She ubsequently had the pseudarthrosis repaired and underwent a supplementary anterior fusion be ause of the increasing kyphotic deformity which developed at he level of p eudarthrosis (ca e 51)

One patient in whom a Harrington rod had not been used had radiological evidence of a pseudarthrosi but she declined further urgery The result was an increa e in her lumbar curve which has now stabilised the p eudarthrosis healed pontaneously and there has been no increa e in the curve beyond the original pre operative deformity four years after surgery (case 47)

n summary a p eudarthrosis was found in only one of the sixteen patients with paralytic scoliosis routinely explored although only three of the e patients had Harrington rods supporting the fusion masses this would appear to be clinical confirmation of the inherent stability of the halo pelvic apparatus

PEL IC OBLIQUITY

Eleven patients with paralytic scoliosis had pelvic obliquity (Table 4) The range of obliquity was from thirty to seventy degrees an average of forty nine d grees The "angle of pelvic obliquity was mea ured from an antero posterior radiograph with the patient seated It is the angle subtended by the line drawn across the top of the first acral vertebral body with the horizontal

Re ults

Pelvic obliquity was correc ed from forty nine degrees (average) to fourteen degrees (average) a correction of 72 per cent At follow up (average 3 3 years later) there had been an average loss of 5 degrees The final correction of pelvic obliquity was therefore sixty-two per cent Only two of the ele en patient had pelvic obliquity

Three patients in Group D (Dwyer's, posterior fusion and rod) with an average curve of 110 degrees corrected to 56 degrees with distraction (49 per cent correction) With Dwyer s operation this was increased to 72 per cent correction with an average loss of 5 degrees at follow-up

Two patients in Group E (posterior osteotomies, distraction and Dwyer s operation) with an initial average curve of 112 degrees had an initial correction of 41 per cent with distraction and a total correction of 49 per cent following Dwyer s instrumentation They lost correction because supplementary posterior fusions were not done The average loss of correction of 17 degrees at the time of follow up demonstrates this point amply

Functional improvement

Seven patients had not been able to walk before surgery because of gross deformities and paralysis in their lower limbs, associated with severe collapsing scoliosis A further seven patients could walk with the aid of long braces and elbow crutches but their walking required such an enormous effort that they preferred a wheelchair existence Of the seven patients who had no walking potential at all two were made to walk by stabilisation of the spine and correction of the pelvic obliquity together with multiple operations on the lower limbs The other five patients were far too extensively involved ever to walk, but as a result of surgery their sitting balance has improved to the point where they do not need their upper limbs for trunk support They are therefore free to sit in a suitable chair at a bench and employ themselves gainfully

Major loss of correction

Seven patients lost more than 10 degrees of correction at the time of follow up Failure to use internal fixation was responsible for this loss in correction in five of these patients the other two had Dwyer s operation without posterior fusions (cases 46 50)

Exploration for pseudarthrosis

Sixteen patients had routine exploration of their posterior fusion masses at least six months after the fusion had been done Fifteen of them were judged to be solid A pseudarthrosis was repaired in one

patient and a Harrington rod was then inserted to protect the newly-added bone graft (case 64)

One patient in whom a Harrington rod was not used developed a pseudarthrosis eighteen months after immobilisation had been discontinued She subsequently had the pseudarthrosis repaired and underwent a supplementary anterior fusion because of the increasing kyphotic deformity which developed at the level of pseudarthrosis (case 51)

One patient in whom a Harrington rod had not been used had radiological evidence of a pseudarthrosis but she declined further surgery The result was an increase in her lumbar curve which has now stabilised the pseudarthrosis healed spontaneously and there has been no increase in the curve beyond the original pre operative deformity four years after surgery (case 47)

In summary a pseudarthrosis was found in only one of the sixteen patients with paralytic scoliosis routinely explored although only three of these patients had Harrington rods supporting the fusion masses this would appear to be clinical confirmation of the inherent stability of the halo pelvic apparatus

PELVIC OBLIQUITY

Eleven patients with paralytic scoliosis had pelvic obliquity (Table 4) The range of obliquity was from thirty to seventy degrees an average of forty nine degrees The angle of pelvic obliquity was measured from an antero posterior radiograph with the patient seated It is the angle subtended by the line drawn across the top of the first sacral vertebral body with the horizontal

Results

Pelvic obliquity was corrected from forty nine degrees (average) to fourteen degrees (average) a correction of 72 per cent At follow up (average 3 3 years later) there had been an average loss of 5 degrees The final correction of pelvic obliquity was therefore sixty-two per cent Only two of the eleven patients had pelvic obliquity

initially fully corrected by the apparatus (Table 4)(see Figs 36 a to d page 106) Pelvic obliquity is a common accompaniment of paralytic scoliosis (11 out of 31 patients) It is seen with muscle imbalance above or below the pelvis (or both)

TABLE 4

PELVIC OBLIQUITY

No of patients	Case No	Pre-operative degree*	Post-traction degree	Correction maintained at follow-up (average 3 3 years)(degrees)
1	46	60	30	42
2	52	63	10	25
3	54	60	0	0
4	56	50	10	10
5	60	40	14	14
6	62	30	20	20
7	63	30	17	17
8	67	40	28	28
9	69	70	10	30
10	71	60	18	18
11	72	35	0	10
Average		49°	14° (72%) (correction of 35°)	19° (62%) (lo s of 5°)

*See text for definition of 'The angle of pelvic obliquity (page 63)

When there is muscle imbalance above the pelvis for example with unilateral paralysis of the lateral trunk flexors a progressive form of scoliosis with pelvic obliquity will develop which in its fully advanced form will lead ultimately to a dislocated hip (Figs 18 a and b)



Figure 18 a Case No 46 Severe collapsing scoliosis in a seventeen year old mile patient Gross pelvic obliquity and dislocating left hip joint Fote that the left iliac crest is almost hori ontal and that the left hip joint is totally unrovered (arrow)



Figure 18 b Case No 46 Following gradual distraction the scoliosis was reduced from 120° to 55° and the pelvic obliquity significantly but rot totally corrected (arrow) Further correction of the pelvic obliquity and scoliosis can only be obtained with anterior surgery

Halo pelvic distraction is a satisfactory method of reducing the scoliosis-pelvic obliquity complex when it is due to paralytic contracture For those patients with walking potential the fullest possible correction of obliquity is an essential aspect of their management A scoliosis fused with thirty degrees of residual spinal curvature will not be particularly significant but thirty degrees of residual pelvic obliquity will be disabling because of the extent to which the higher hip joint has been uncovered For patients with limited walking potential covered hip joints are essential

The reason for this inability to correct pelvic obliquity totally with halo-pelvic distraction (only 2 out of 11 had total correction of the obliquity) is as follows whilst the soft tissues on the concavity of the scoliosis are shortening, there is increased compression on the concave aspects of the vertebral end plates reducing growth Less compression on the convex sides of the end plates of the vertebral bodies produces relatively more growth the end result is that the vertebral bodies become wedge shaped Halo-pelvic distraction will overcome the soft tissue contracture but will not alter the shape of the vertebral bodies this car only be refashioned by a direct approach ideally by Dwyer s anterior instrumentation (Figs 19 a and b)

With preliminary traction followed by Dwyer s anterior instrumentation the pelvic obliquity can in many cases be totally corrected When the scoliosis includes the fifth lumbar body, the anterior instrumentation should extend as far distally Extensive posterior fusion extending to the sacrum is then required to avoid a recurrence (38)

Should one consider using halo pelvic distraction in pelvic obliquity the altered anatomy of the iliac crests must be taken into consideration There is a definite risk of perforation of the intestines when inserting the pelvic pins in such patients The thoracic cage may often be intra pelvic in the extreme types and the safest method if the halo pelvic apparatus is to be used may be firstly to apply halo-femoral traction so that part of the obliquity can be overcome before inserting the pelvic pins which can then be done with greater safety



Figure 19 a Pre operative standing radiograph Note the dislocating right hip joint (arrow) associated with the pelvic obliquity



Figure 19 b Anterior posterior radiograph three years after corrective surgery (Dwyer s anterior surgery distally to L5 and posterior spine fusion) Note the right hip joint is now reasonably well covered (large arrow) The pelvic obliquity has been well corrected and fusion extends to the sacrum (small arrow)

Figure 19 (a) and (b) Case 56 Fourteen year old male patient with severe lumbar scoliosis and pelvic obliquity

31 patients with paralytic scoliosis commenced treatment in the halo-pelvic apparatus 24 completed treatment the other 7 included 1) 4 patients with previously fused spines these will be discussed in the Salvage group 2) 3 patients with pelvic obliquity had early removal of the halo-pelvic apparatus because of poor pelvic pin fixation The average flexibility was 25 per cent in the suspension film (full body weight suspension) the average number of vertebrae in the major curve was 9 The average length of follow-up was 3 3 years

As a correcting device, the halo-pelvic apparatus achieved an average correction of 51 per cent (range 24 to 81 per cent) for patients with an average paralytic scoliosis of 111 degrees

The actual methods of fusion were posterior fusion without rodding, 11 patients and with rodding, 3 patients Posterior fusion without rodding and with a supplementary Dwyer s operation 5 patients posterior fusion and rodding with Dwyer s operation 3 patients and Dwyer's operation with posterior osteotomies, 2 patients

The average loss of correction was 10 degrees The loss tended to be less in those patients with internal fixation and those where supplementary anterior surgery (Dwyer instrumentation) was employed

40 per cent of the patients with paralytic scoliosis whose cervical spine radiographs were reviewed showed evidence of degenerative changes they will be discussed under Complications

11 patients in the series treated by the halo-pelvic apparatus had associated pelvic obliquity In only two was that obliquity totally corrected initially When pelvic obliquity is present and has not been sufficiently corrected Dwyer s anterior instrumentation should be considered because of the importance of adequately covering both hip joints particularly in patients with walking potential

The available evidence suggests that the halo pelvic apparatus can be relied on to achieve an initial average correction of 51 per cent in paralytic scoliosis and 71 per cent of associated pelvic obliquity It has a significant part to play in those patients with poor

respiratory reserve

3 IDIOPATHIC SCOLIOSIS

Introduction

There were 15 patient with idiopathic scoliosis treated by the halo pelvic apparatus 4 patients had had previous surgery (cases 75 82 86 87 see appendix B) and they will be discussed separately in the Salvage group

There was 1 male and 14 females and their average age at the time of surgery was 15 6 years The average time spent by these patients in the halo pelvic apparatus was 6 4 months (range 1 to 12 months)(Fig 20) Their follow up ranged from 1 5 years to 3 years (average 2 4 years)

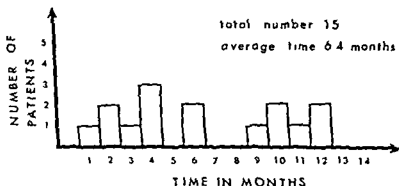


Figure 20 Idiopathic scoliosis Barograph demonstrating the time spent by the patients in the apparatus Average time was 6 4 months

The average curve before surgery measured from pre operative standing radiographs was 82 degrees (range 47 to 97 degrees) Barograph of the vertebrae included within the major curve (Fig 21) demonstrates that the vertebral levels T10 and T11 were the most frequently involved An average of seven vertebrae were included in each major curve

SUMMARY AND CONCLUSIONS

31 patients with paralytic scoliosis commenced treatment in the halo-pelvic apparatus 24 completed treatment the other 7 included 1) 4 patients with previously fused spines, these will be discussed in the Salvage group 2) 3 patients with pelvic obliquity had early removal of the halo-pelvic apparatus because of poor pelvic pin fixation The average flexibility was 25 per cent in the uspension film (full body weight suspension), the average number of vertebrae in the major curve was 9 The average length of follow up was 3 3 years

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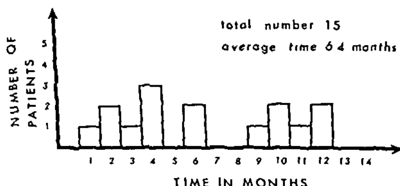


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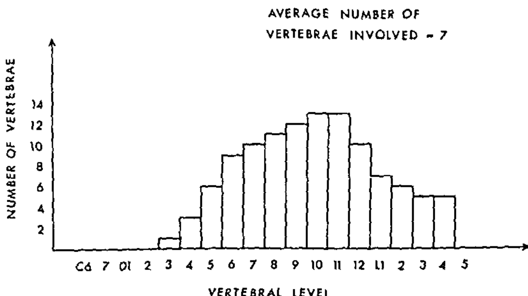


Figure 21 Barograph to demonstrate the vertebrae involved in the major curve in idiopathic scoliosis The average number of vertebrae involved was 7

The indication for the use of the apparatus in this series was in most instances, a rigid deformity associated with a marked rotational component The average age of the patients (15 6 years) suggests that the deformity had been present for some years and had developed significant vertebral body wedging which cannot be corrected by distraction

METHODS OF TREATMENT

Halo pelvic distraction over an average period of nine weeks (range 3 to 10 weeks) was followed by a one stage posterior fusion in seven patients and a two staged posterior fusion in one patient (case 74 with a double primary curve of 97 degrees) Harrington rods were used in five of the eight patients without further significant correction the principle being to achieve the major correction before surgery Following distraction three patients had Dwyer s anterior instrumentation without posterior fusion

RESULTS

The average curve after distraction measured 48 degrees a correction of 42 per cent The best final corrections were obtained in the two *patients (cases 78 85 lumbar scoliosis)* who had Dwyer s instrumentation performed after distraction *Both corrected to zero* The third patient with Dwyer's instrumentation had a thoracic scoliosis which lost nine degrees of correction after surgery

One patient (case 81) *in whom the upper hook* slipped out lost 17 degrees of correction Two pa ients in whom internal fixation was not used (cases 76 77) lost 10 degrees of correction Case 77 actually lost correction whilst in the apparatus for a period of 10 months Lo s of correction *will be discussed under Complications* (Part II Chapter II)

Nine patients had cervical spine radiographs taken four pa ients *(44 per cent) developed cervical spine complications as the result* of the halo pelvic distraction these will be discussed more fully in the section dealing with complications

SUMMARY IDIOPATHIC SCOLIOSIS

Eleven patients with idiopathic scoliosis who had not had previous surgery had their curves corrected before fusion by the halo pelvic *apparatus Their average age was 15 6 years and the average major curve measured 82 degrees* The average correction was 42 per cent and following this eight patients had posterior surgery with or without internal fixation whilst three had Dwyer s anterior instrumentation performed

4 CONGENITAL KYPHOSCOLIOSIS

Clinical material

There were ten patients with congenital spinal deformities *four* males and six females one patient died *with respiratory failure* after surgery The average age at the time of surgery was 13 8 years

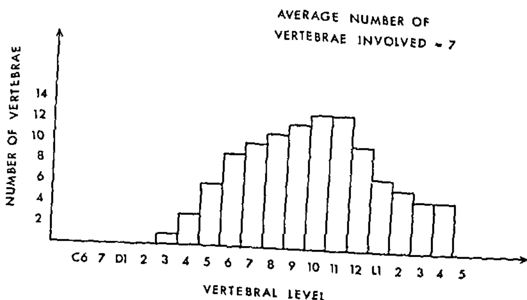


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One patient developed a pseudarthrosis which required further surgery (case 97) This patient s curve deteriorated finally to its pre operative level of deformity

5 NEUROFIBROMATOSIS

Clinical material

Six patients with neurofibromatosi were treated with the halo pelvic apparatus two males and four female Three of the six patients were paraplegic on admission following previous surgery they had been paraplegic for one week three weeks and five months re pectively

The average length of time in the halo pelvic apparatus was 8 months (Fig 23) the average length of follow up was 3 years (range 2 to 4 years)

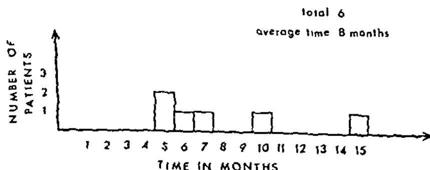


Figure 23 Neurofibromatosis Length of time in halo pelvic traction

The average number of vertebrae involved in the major curve was 8 the barograph demonstrates a peak of vertebral involvement at thoracic 9 10 levels (Fig 24)

(range 10 to 19 years) Two patients were paraplegic on admission one of them became paraplegic when correction of the deformity was attempted on a standard traction table in another centre The average time in the halo-pelvic apparatus for these patients was 5 5 months (range 3 to 9 months) (Fig 22)

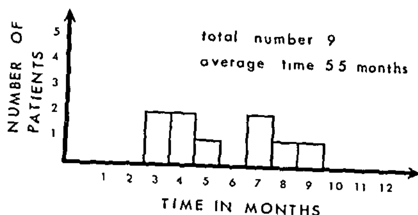


Figure 22 Congenital kyphoscoliosis Length of time in halo pelvic distraction

The average degree of coliosis measured was 98 degrees The halo-pelvic apparatus wa used as a means of external spine fixation in two patients to provide stability after surgery so that in neither case was any correction attempted

METHODS OF TREATMENT

The two patients with congenital deformities and cord compression had decompression done Eight patients had mobilising osteotomies and five subsequently had staged anterior and posterior fusion following distraction Two patients had Harrington rods inserted and one had a Dwyer s instrumentation performed

RESULTS

The percentage correction in the congenital deformities was 26 per cent (range from 6 to 48 per cent)

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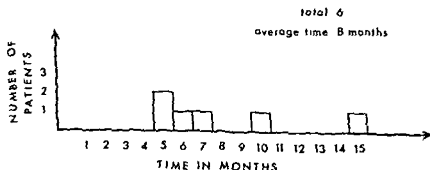


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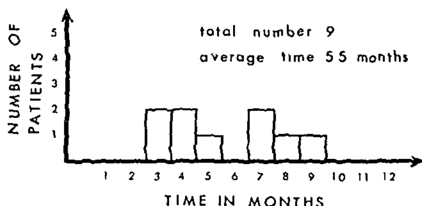


Figure 22 Congenital kyphoscoliosis Length of time in halo-pelvic distraction

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RESULTS

The percentage correction in the congenital deformities was 26 per cent (range from 6 to 48 per cent)

he loss of correction even after anterior and posterior fusions was significant Whilst initial corrections were good the subsequent loss of correction left much to be desired confirming the tendency of patients with this syndrome to deteriorate in spite of staged anterior and posterior fusions Eighteen months after surgery case 102 lost 50 degrees of correction with stress fractures through both anterior and posterior grafts which occurred despite radiologically sound fusions

SUMMARY AND CONCLUSIONS CONGENITAL AND NEUROFIBROMATOSIS KYPHOSCOLIOSIS

Fifteen patients with congenital or neurofibromatosis spinal deformities completed treatment in the halo pelvic apparatus One patient died after surgery because of respiratory failure Five of the fifteen patients (33 per cent) had cord compression or frank paraplegia at commencement of treatment Two of these patients had had previous extensive laminectomies performed The basic plan of treatment depended on the basic configuration of the spinal deformity and the presence or not of spinal cord compression Following decompression (when it was required) anterior and posterior fusions were used in the majority of patients In the congenital curve the average correction of the deformity was 26 per cent and in the neurofibromatosis patients the average correction was 43 per cent All had complete or near complete return of cord function and could walk six months after spinal surgery except for case 99 where complete paraplegia had been present for five months before treatment (5 years later she had shown no further recovery)

Many of the associated conditions represented by this group of patients present ideal indications for the use of halo pelvic apparatus namely spinal cord compression gross spinal curvatures an unstable spine secondary to extensive laminectomies and the association of respiratory impairment

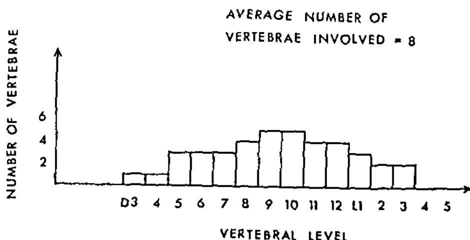


Figure 24 Neurofibromatosis Barograph to demonstrate the vertebrae involved in the major curve

METHOD OF TREATMENT

Of the six neurofibromatosis patients the three who were *paraplegic* on admission had anterior decompression done followed by anterior fusion (after distraction in two patients)

The three patients without cord decompression had staged anterior and posterior fusions following distraction *(2 patients)* and a posterior fusion following distraction (1 patient)

RESULTS

The average correction of patients with neurofibromatosis deformities was 43 per cent (range 6 to 85 per cent) Of the three *patients* who were paraplegic on admission two recovered cord function and were able to walk 6 months after decompression and fusion The third patient (case 99) had been paraplegic for five months before surgery by which time her cord function was irreversible

major values offered by the halo pelvic *apparatus* in certain situations particularly that of associated pelvic obliquity and *respiratory* insufficiency

TABLE 5

CORRECTIO(OF PREVIOUS FAILED FUSIONS (SALVAGE GROUP)

TABLE 5

CORRECTION OF PREVIOUS FAILED FUSIONS (SALVAGE GROUP)

No	Sex/Age	Number of operations	Operations *performed*	Time in HPT *(months)*	Correction From To (degrees)	Final (degrees)	Length of follow up (years)
A PARALYTIC SCOLIOSIS							
43	M/11	2	SO				
			PSF	7	97 74 24%	97	4 75
61	F/18	2	ASF				
			PSF (rod)	7	28 20 29	20	3 0
70	F/13	4	PSO (2 stages)				
			PSF (2 stages with rod)	8	110 50 55	70	2 0
73	F/14	2	PSO)Comb PSF) ASF	3	Holding		1 5
B IDIOPATHIC SCOLIOSIS							
75	F/18	1	PSF	12	75 33 56%	33	3 0
82	F/9	2	ASF	9	94 57 39%	57	2 0
86	F/15	1	PSO (one stage with rod)	3	62 52 16%	52	2 0
87	F/13	2	PSO				
			PSF (rod)	4	92 48 48	48	1 5

SUMMARY AND CONCLUSIONS SALVAGE GROUP

Eight patients *with previous posterior* fusions for scoliosis had the halo pelvic apparatus used in their treatment In two it was used for external skeletal fixation and in six patients to correct deformities following osteotomies and prior to fu ions Three patients had supplementary anterior fusions The average correction with the halo pelvic apparatus was 40 per *cent*

6 SALVAGE GROUP

Eight patients with previous posterior spinal fusions for scoliosis were treated by the halo-pelvic apparatus

The average time in the apparatus was 6 5 months The average pre-operative curve in this group was 88 degrees Two patients excluded from the average include case 73 who had initial correction following osteotomies with halo-femoral traction and case 61 whose basic deformity was a kyphosis, which developed acutely at the site of a pseudarthrosis (paralytic scoliosis) The average follow-up was 2 5 years (range 1 5 to 4 7 years)

METHOD OF TREATMENT

Following fitting of the apparatus the previous fusion mass was explored and any metal present was removed Usually a Harrington rod, if it had been used had fractured at the site of pseudarthrosis and had caused loss of correction Osteotomies were done at the apex of the curve and distraction was applied over the next few weeks

At re operation the osteotomy sites were grafted and internal fixation with the Harrington rod was used (four patients) Three patients had supplementary anterior fusions performed (Table 5)

RESULTS

The average curve after correction was 52 degrees a correction of 40 per cent An average of two spinal operations was performed per patient The one specific problem in using the halo-pelvic apparatus in this group of salvage cases was that the pelvic pins precluded the use of graft from the posterior parts of the iliac crests It is in these patients however that large blocks of cancellous bone grafts are often required to plug the gaps created at the levels of the fusion mass osteotomies

This factor however may be of minor importance relative to the

CHAPTER II COMPLICATIONS

INTRODUCTION

The incidence of complications has been greatly reduced by the increased experience in the u e of the halo pelvic apparatus Improvements in the technique of fitting the apparatu and the introduction of force measurements together with refinements in the clinical care of the patients have all contributed to a lo er complication rate more recently

There are several complications however which inevitably occur with the use of the halo pelvic apparatus such as osteoporosis loosening of the pelvic pins and problem with distraction in the cervical spine

In the initial stages of experience with the halo pelvic apparatus complications occurred which led to changes and refinements in the procedure All the complications encountered during the treatment of the first 104 patients with the halo pelvic apparatus have been listed (Table 6 page 60) It is hoped that discu sion of past mistakes will eliminate unnece sary complications The author believes that strict adherence to the detailed instructions itemised in Part I sh uld prevent many of these complications from being repeated

COMPLICATIONS RELATED TO THE SKULL HALO

Infected halo pins

These occurred in 20 out of 104 patients and required replacement This is an easy matter with the modified halo in use which has multiple threaded holes around its perimeter and allows a wide selection of alternative pin sites (Fig 2 page 17) In one patient an intense cellulitis developed in a pin site and for fear of a cavernous sinus thrombosis developing the halo and extension bars were removed until the infection had subsided

A chronic discharging sinus following removal of the skull halo occurred in 2 patients Radiographs revealed a small bony sequestrum

which was removed by currettage, and the drainage subsided

Slipping skull halo

In 8 patients the halo slipped off and both the halo and extension bars needed to be replaced under general anaesthesia The skull pin should be checked with the torque screw driver one week after fitting and tightened up if necessary Much bone resorption will often have occurred around the point of the skull pins due to pressure necrosis and they sometimes require several turns of the screw driver to return them to 5 5 pound inches (0 06 kpm) of torque force

Once the halo has begun to slip off it is difficult to replace particularly if there is much tension in the extension bar It is a painful and frightening occurrence for the patient for which he requires adequate analgesic If only a couple of millimetres of slipping has occurred then with local anaesthetic infiltration supplementary skull pins can be applied providing that the skin around the existing skull pins is not excessively tented and ischaemic

Should the halo have slipped further than can be accepted it is best removed together with the extension bars to allow the patient to settle down It can then be reapplied several days later under local or general anaesthesia When a patient complains of looseness or slipping of the skull halo it is important to act immediately or the halo will continue to slip rapidly accelerated by the high forces being used The incidence of skull halos slipping has been greatly reduced by using six pins and by checking their tension one week after fitting These are now used routinely for heavier patients and patients requiring longer periods of treatment

COMPLICATIONS RELATED TO THE PELVIC PINS

Torn peritoneum

This occurred in one patient (case 71) who had a collapsing paralytic scoliosis (1?6 degrees) associated with pelvic obliquity of 60 degrees His clinical picture will be given in some detail because of the serious nature of the complication

TABLE 6

COMPLICATIONS DUE TO TREATMENT WITH THE HALO PELVIC APPARATUS

	Total number of patients (104)	Per cent
1 Related to skull halo		
1 Infected halo pins	20	21
2 Chronic discharging sinus	2	2
3 Slipped halo	9	8
2 Related to pelvic pins		
1 Torn peritoneum	1	1
2 Infected and loose pins	50	50
3 Premature removal	5	5
4 Ischial tuberosity pain	5	5
5 Sensory nerve syndromes	3	3
6 Hip contractures	3	3
7 Broken pelvic pins	2	2
3 Spinal cord and nerve injuries		
Spinal cord		
Temporary spasticity	3	3
Cranial nerve neurapraxias (all temporary)		
Sixth (VI)	2	2
Tenth (X)	4	4
Twelfth (XII)	1	1
Brachial plexus lesions (all temporary)		
C5 6	2	2
T1	1	1
4 Cervical spine (77 patients with radiographs)		
Acute over distraction		
Avulsion ring apophysis	1	0 8
Chronic distraction		
Avascular necrosis upper pole dens	13	17
Subluxation of atlanto axial joint	5	6
Prolonged immobilisation		
Degenerative posterior joints	26	34
Spontaneous fusion upper units	1	0 8
5 Intestinal obstruction	3	3
6 Osteoporosis	100	100
7 Miscellaneous		
1 Deaths (post operative)	4	4
2 Pressure sore over the kyphos or rib hump	5	5
3 Infection (wound)	3	3
4 Psychological disturbance	Nil	Nil

which was removed by currettage and the drainage subsided

Slipping skull halo

In 8 patients the halo slipped off and both the halo and extension bars needed to be replaced under general anaesthesia The skull pins should be checked with the torque screw driver one week after fitting and tightened up if necessary Much bone resorption will often have occurred around the point of the skull pins due to pressure necrosis and they sometimes require several t rr of the screw driver to return them to 5 5 pound inches (0 06 kpm) of torque force

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COMPLICATIONS RELATED TO THE PELVIC PINS

Torn peritoneum

This occurred in one patient (case 71) who had a collapsing paralytic scoliosis (126 degrees) associated with pelvic obliquity of 60 degrees His clinical picture will be given in some detail becau e of the serious nature of the complication

The pelvic pin on the higher side of the pelvis could be palpated during its insertion both on the inside and the outside of the crest, indicating the thinness of the bone

He vomited several times that evening and complained of abdominal pain 24 hours later his temperature was 37 8°C and his pulse 100 per minute He did not complain of much abdominal pain, but there was generalised abdominal tenderness, reflex abdominal guarding was not possible because of the extensive muscle paralysis A plain erect radiograph of the abdomen showed some gas beneath the diaphragm

Bowel perforation was considered likely and an exploratory laparotomy was done immediately The pelvic hoop was removed but the two pins were left in position A left paramedian incision was made and the findings were as follows There was no bowel injury, both caecum and sigmoid colon were several centimetres from the pins The right pin had torn a hole in the peritoneum measuring 2 by 2 centimetres, and approximately 30 millilitres of blood had trickled from that iliac crest through the rent in the peritoneum producing the clinical signs of peritonitis The left pelvic pin could be felt and seen from inside through the peritoneum It had produced a haematoma in the iliacus muscle The tear in the right iliac fossa peritoneum was repaired, the blood stained fluid was aspirated from the cavity and the abdominal wall closed in layers The pelvic hoop was then re-applied Subsequently the patient had no further problems

After insertion of the pelvic pins, all patients must be observed closely for 24 hours and should there be any fear of bowel perforation a general surgeon must be consulted immediately If a laparotomy is done it is best to leave the pins in situ until the pathology is fully identified

The intestinal surgery required will depend on the site and extent of the gut damaged as well a the delay in diagno is Perforations of the small intestine caecum or sigmoid colon should be oversewn and the surrounding area drained If there has been extensive injury to the caecum or sigmoid colon a right or left hemi colectomy should be done In the case of the sigmoid colon, a proximal transverse colostomy or caecostomy should be done in addition to the left hemi-colectomy (49)

There has been no instance of bowel injury in this series although it has occurred on several occasions in other centres The danger with pelvic obliquity is apparent The anatomy of the bony pelvis is so grossly abnormal and the bone so poorly developed and osteoporotic that a large portion of the pin may be intrapelvic

Infected and loose pelvic pin

The pelvic pins commonly drained at some stage of treatment this was usually a clear serous discharge and cultures taken were often negative The skin around the pelvic pin occa ionally grows up around the pin and in many patients the pin sites remained dry for many months It is important however that they be examined and dressed each day and cultures taken if the discharge becomes profuse or purulent the patients a tivities should then be restricted and antibiotics considered Prophylactic antibiotic treatment should also be considered although it was not used routinely in thi series

Patients with paraplegia and anaesthetic skin around the pelvic pins had a greater tendency to infection than those with normal skin sensation

There has been no osteomyelitis of the ilium but there have been several patien in whom a continuing discharge has become a problem In this respect the possibility of cross infection must be remem bered and if the patient is being nursed in a large ward he should be isolated

M thods of minimising the occurren e of infection include
1) applying the pelvic pins accurately and with a minimum of trauma
2) the anterior point of entry chosen at or very near the tubercle of the crest is subcutaneous and therefore has the least volume of soft tissue to rub against the pin If any point below this is chosen the pin will penetrate the abductor muscle mass and the constant rubbing of the pin again t the muscle could produce continual discharge
3) the thicker the pin the less will be its excursion and the less irritation it will produce in both bone and soft tissue The quality of the pin itself is important It must be high quality surgical stainless steel titanium is an ideal implant but it is too

malleable for this purpose except for the lighter patients 4) the constant friction of skin and subcutaneous fat against the pelvic pin can be minimised by a collodin dressing which reduces the movement of the skin around the pin The longer the pelvic pins are in position the wider the tracks they create within the crests This is for several reasons a) there is constant sawing of the pin thread against the cancellous bone, b) immobilisation osteoporosis occurs above the pelvic pin with resulting resorption of bony trabeculae In some instances the "windscreen wiper effect will be seen in radiographs after several months (Fig 25)

Two patients early in the series had loose pins replaced, but this is felt to be unwise, as the initial pin may have produced adhesions to the pelvic viscera and the introduction of the second pin may expose the bowel to an increased risk of injury

Premature removal of the pelvic hoop

Five patients required early removal of the apparatus for the following reasons one patient had decided not to continue with his treatment three patients had inadequate purchase of the pins in the pelvic bone, (these patients all had severe degrees of pelvic obliquity associated with paralytic scoliosis) Another patient with pelvic obliquity had begun to sit up for the first time and the anaesthetic skin over one ischial tuberosity had broken down and become infected necessitating extensive plastic surgery before spinal surgery could be considered He like the others ultimately had a combined anterior and posterior correction and fusion

Ischial tuberosity pain

This occurred in five patients They had usually been in the apparatus for several months and complained of pain in the region of the tuberosity which was tender to palpate There may be no sign of infection either there or around the appropriate pelvic pin It is possible that the pin was irritating the sacro iliac joint with pain referral to the region of the tuberosity

Sensory nerve irritation

Three patients in the later stages of distraction developed pain in the anterior region of the thigh The femoral nerve in its cour e

within the pelvis lies in the groove between the iliacus and psoas muscles i s surprising how close the pin may be to the femoral nerve if the mid part of its course is intrapelvic One possibility is that inflammatory oedema produced by the pin irritates the cutaneous component of the nerve and produces pain

The other possibility i that the lumbar nerve roots are being over-stretched with production of sensory disturbances Sunderland (59) has noted that when a mixed nerve is stretched there is never motor disability without sensory loss sometimes there may be altered sensation alone

Paraesthesia of the lateral cutaneous nerve of the thigh was observed in two patients In the first few patients in the series the pelvic pins were being inserted just lateral to the anterior superior spine and presumably the lateral cutaneous nerve of the thigh where it emerges just medial to the anterior superior iliac spine was irritated at the point where it emerged from the pelvis and produced paraesthesia   This was of no consequence and in both the affected patients it settled within several weeks

Hip contracture

The point of insertion of the pelvic pin is immediately above or at the upper fibres of origin of the tensor fasciae latae In paralytic patients who have been in the apparatus for several months this tissue will contract Alternatively if the pin is intrapelvic in its mid portion and therefore related to the fibres of origin of the iliacus a flexion contracture may be produced by contracture of the ilio p oas complex

On three occasions flexion abduction contractures required division when the halo pelvic apparatus was removed Some patients favour moving about in a wheelchair during treatment whilst this is acceptable they must not be permitted to sit all day as severe contractures will develop Their hip joints should be placed through a full range of passive movement each day to prevent these contrac tures occurring (39)

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Three patients in the later stages of distraction developed pain in the anterior region of the thigh The femoral nerve in its course

disease process This phenomenon has been emphasised by Hodgson and co workers (28) and i clinically manifest by severe lower limb clonus and spasm

Discussion

The spinal cord begins a the lo er end of the medulla oblongata and is described as extending normally to the intervertebral disc between the first and second lumbar bodies although this is variable (29) In patients with long standing deformities with congenital absence or infective destruction of the vertebral bodies one cannot judge exactly where the spinal cord terminates The cord occupies the shortest course within the spinal canal in scolio is i will re t against the concavity and in kyphosis it will o cupy an anterior position in the canal abutting against the internal kyphos

The blood supply of the spinal cord has been a subject of increasing interest the cord is nourished by three longitudinal vessels which extend from the origin of the cord to the conus medullaris they are two postero lateral arteries and a larger anterior spinal artery (29) This latter vessel receives contributions along its course which are not segmental however the most important member of these so called feeder vessels is the artery of Adamkiewicz (1) which occurs on the left side in 80 per cent of patients and most frequently at about T10 vertebral level

Prompted by a high incidence of paraplegia following operation for severe scoliosis in adults Dommisse (13) investigated the blood supply of the spinal cord and the dimensions of its canal He concluded that the blood supply is poorest and the spinal canal narrowest from the T4 to approximately the 9 vertebral level This region he named the critical vascular zone of the spinal cord

Breig (2) has demonstrated that the spinal cord shortens and lengthen to accommodate relative changes in the length of the spinal canal He analysed the relative a o nts of lengthening which occurred in different areas of the cord the thoracic cord was least extensible (one centimetre) the lumbar cord intermediate (one to two centimetres) and the cervical cord most able to be deformed (1 8 to 2 8 centimetres) Three quarters of the physiological extension was provided

Broken pelvic pins

The pelvic pin may break either within the crest itself or externally between the skin and the pelvic hoop There have been two fractures of a pin adjacent to its attachment to the pelvic hoop and this has not presented particular difficulties If the pin breaks within the pelvis, then it must be replaced unless treatment is near completion when consideration may be given to removing the apparatus a little earlier than planned

SPINAL CORD AND NERVE INJURIES

Paraplegia

No patient sustained permanent paraplegia as a result of distraction Three patients had episodes of temporary spasticity and lower limb weakness during the course of treatment, one associated with coning of the brain stem into the foramen magnum The circumstances under which these temporary cord signs occurred were as follows

1 Case No 12 developed fever papilloedema headaches and hyper tension following anterior and posterior osteotomies and distraction to correct a previously fused severe high dorsal tuberculous kyphosis A lumbar puncture excluded meningitis The symptoms settled when the distraction bars were shortened by 5 millimetres Some weeks later he developed lower limb spasticity and this again was completely relieved by shortening the extension bars further

2 Case No 74 with a severe double primary idiopathic scoliosis had some temporary motor loss in her lower limbs following posterior fusion In retrospect the tension left on the spine during surgery resulted in a taut spinal cord which was exposed to the risk of concussion

3 Case No 17 with severe tuberculous kyphosis and pre operative partial paraplegia had a short temporary episode of increased leg weakness following posterior osteotomy

Cases 31 33, 34 - three patients with severe pre-operative spasticity were permanently paraplegic following surgery In no case was distraction an etiological factor All three had severe tuberculous kyphosis with penetration of the spinal cord by the tuberculous

In posterior urgery this will mean removing the two posterior bars and shortening the two anterior bars by 5 to 10 millimetres each or removing all the bar The correction lost by releasing this tension will be negligible

Cranial nerve neurapraxias

Seven patients developed cranial nerve palsies during treatment the sixth cranial nerve in two patients the tenth cranial nerve in four patients and the twelfth cranial nerve in one patient All were temporary and recovered rapidly except for the twelfth nerve injury (case 91) which took one year before recovery was complete

Traction generated and transmitted during extension falls mainly on nerve pursuing vertical or obliquely vertical ourses and this would explain the selection of nerves which ustain traction injuries with halo pelvic di traction (58)

The abducent (VI) nerve runs upwards and is fixed where it leaves the pon o medullary junction and where it cros es the apex of the petrous temporal bone The vagus (X) and hypoglossal (XII) cranial nerves run slightly upwards to leave the skull by way of the jugular and hypoglos al foramina re pectively Glo so pharyngeal (IX) fun tion is normally not tested but is closely as ociated with tenth and twelfth cranial nerves in the area of vulnerability at the base of the skull it is presumably involved in many of these patients though its njury is more of anatomical than clinical significance

Bra hial plexu lesion

Two patients sustained neurapraxias of the C5 6 nerve root and one of the first thoracic nerve root The e three temporary lesion occurred towards the end of distraction in patients with rigid deformities The fifth and ixth cervical pine nerve are more obliquely aligned in the neck and therefore more prone to injury by a vertically transmitted distraction force The first thoracic nerve crosses the neck of the first rib and presumably here it is tented and stretched by the distraction

The clinical significance of these nerve injuries is that no further correction can be achieved unless one mobilises the pine with

by unfolding of the cord and the remainder through the natural elasticity of the tissue

The spinal cord is at risk with any form of rapid spine distraction because its axis is parallel to the longitudinal forces generated With the cord under tension, Sunderland (58) noted mechanical failure occurring at values of 0 66 kp/mm^2 with a rate of extension of three inches per minute Such a rate of extension in clinical circumstances could probably only be applied to the cord if the patient were forcibly corrected under general anaesthesia whilst applying distraction with the extension bars

The lower thoracic cord would thus seem to be its most susceptible area and it is in this region that most spinal deformities have their peaks of incidence as the barographs demonstrate (Appendix A) It is also normally a rigid region of the spine where antero posterior and side to side motion permitted are approximately only 2 to 6 degrees at each segment (62)

Several factors must be remembered if paraplegia is to be avoided Pre-operative assessment should include myelography in order to exclude or to define an intraspinal lesion or to delineate the level and extent of cord compression particularly in kyphoses and all congenital lesions There may well be myelographic evidence of a narrowed spinal cord without the obvious clinical signs of an upper motor neurone lesion as for example with tuberculosis Should cord compression be detected it must be removed to allow safe correction with gradual distraction

It is prudent to carry out a daily neurological assessment whilst carrying out distraction which must be gradual and well tolerated by the patient (Table 1 page 34) Regular lateral radiographs of the cervical spine and force measurements assist in determining a safe rate and tolerable extent of distraction

Patients with cord compression are in the greatest risk category particularly if in the cases of tuberculosis the disease has penetrated the spinal cord There is a high risk of paraplegia if one operates on a patient with a spinal cord under excessive tension therefore the tension should be released at the time of operation

The duration of the paralysis varie from patient to patient and bears no constant relationship to the cause or the apparent severity of the injury

COMPLICATIONS IN THE CERVICAL SPINE

77 patients in this series had radiographs of the cervical spine taken at some stage during treatment or at the time of the follow up 45 patients had cervical spines which were regarded as radiologically normal 32 patients had radiologically abnormal cervical spines These abnormal radiological findings included

1) Degenerative changes in the posterior joints of the cervical spine the main features of which were diminution of the joint space erosions and cystic lesions of bone adjacent to the joint Such latter changes were sometimes seen whilst the patient wa still in the apparatus (26 patients)

2) Avascular necrosis of the proximal pole of the dens This was evidenced by cystic areas in the proximal end of the dens by irre gularity of the contour of the pole and adjacent sclerosis (13 patients)

3) Chronic atlanto axial subluxation This was confirmed by lateral flexion and extension radiographs of the cervical spine and was found in five patients at the time of follow up

4) Avulsion of the ring apophysis of the inferior body of the second cervical vertebra occurred in one patient as a result of rapid distraction (Fig 26)

Of tho e with avascular necrosis of the den (13 patients) ten had treatment for tuberculous kyphosis and one each for idiopathic neuro fibromatosis and paralytic scoliosis respectively (60) Of these 13 patients with avascular necrosis of the dens 7 had associated degenerative changes in the posterior joints

In a previous report (48) 65 per cent of the patients (44 out of 70) were observed to have developed change in the cervical spine Loss of normal cervical lordosis was then considered abnormal In a later review of more radiographs many were found to have regained much of the normal lordosis and when no other changes were apparent and no clinical symptons pre ent they were reclassified as normal

osteotomies and considers resuming traction thereafter Even when this is done, the nerve injury is likely to recur when the same amount of distraction force is built up again, as occurred in the patient who sustained the hypoglossal nerve injury This same observation has been made by DeWald (11) If these injuries are recognised very early and the extension bars shortened, then the prognosis for quick recovery is excellent

The tensile strength of a nerve trunk depends essentially on its perineurium tension in deforming nerve fibres will interfere with their blood supply Studies in stress and strain have shown that the greatest elongation within the elastic limit is 20 per cent except for some nerves where it may be as low as 6 per cent (59) The rate of application of deforming forces as well as their magnitude are instrumental in producing nerve lesions When distraction is applied over a long period of time nerves can be stretched well beyond the range of elasticity with little or no disturbance of function

As the bundles elongate the nerve fibre deformation may produce arrest of circulation and obliteration of the vessels in the stretched nerve (59) Lundborg and Rydevik (32) demonstrated the effects of stretching the tibial nerve of the rabbit The first vessels to be affected were the venules There was arrest of venular flow with about 8 per cent elongation at which stage there was the first intravasal evidence of tissue injury granulocytosis microthrombi and emboli

Temporary nerve injuries involve interruption of conduction with preservation of anatomical continuity These types of nerve injury have been termed first degree injuries by Sunderland (59) and neura praxias by Seddon (56) In some cases conduction may be arrested on the verge of paralysis so that only a paresis results

Most paralysed muscles will show recovery within six weeks Sunderland (59) reported a series of patients with a duration of paralysis ranging from 17 to 60 days Seddon (57) observed that mild distraction produces a lesion clinically indistinguishable from neurapraxia the fibres are affected in order of their size motor paralysis is complete and sensory disturbance minimal Recovery occurs rapidly and completely

The duration of the paralysis varies from patient to patient, and bear no constant relationship to the cause or the apparent severity of the injury

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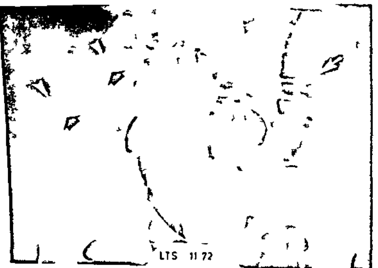


Figure 25 Case 98 Antero-posterior radiographs of pelvis after the patient had been in the apparatus for seven months Note 1) the widening of the pin tract within the iliac crest the so-called windscreen wiper effect (arrows) 2) marked osteoporosis of the iliac crests above the pin tracts 3) on the viewer s right side gas in the sigmoid colon overlying the left pelvic pin tract provides a good demonstration of the relationship of the sigmoid colon to the iliac crest (arrow)

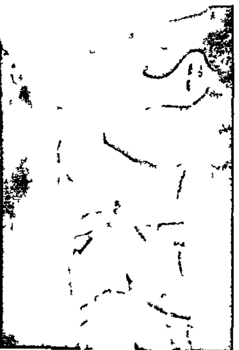


Figure 26 Case 16 Lateral radiograph of upper cervical spine to demonstrate avulsion of the ring apophysis of the inferior aspect of the second cervical vertebra due to rapid distraction

,evertheless the incidence of radiological changes in the cervical spine is high

Fo r particular factors were analysed to determine their significance in relation to these above mentioned radiological cervical spine complications taken as a whole The factors analy ed were a) the age of the patient b) the period of time in the apparatus, c) the etiology of deformity and d) the corrective forces used

_e a e of the pati nt

Tho e patients with radiologically abnormal cervical spines were grouped mainly between 11 and 21 years 11 patients younger than 10 years had no radiological changes at time of follow up (range 2 to 5 year) (Fig 27)

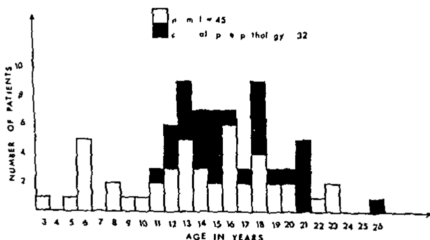


Figure 27 Barograph to demonstrate the age of patients with radiological change in the cervical spine after treatment in the halo pelvic apparatu

There appeared to be a trend towards an increa e in neck pathology correlating with the age of the patient (Fig 28)

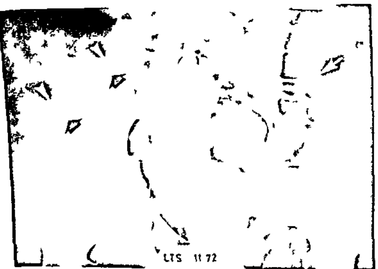


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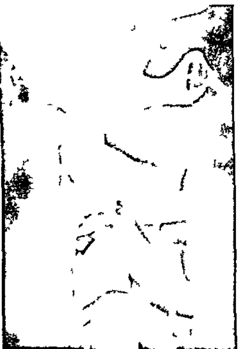


Figure 26 Case 16 Lateral radiograph of upper cervical spine to demonstrate avulsion of the ring apophysis of the inferior aspect of the second cervical vertebra due to rapid distraction

There were quite a definite trend regarding the incidence of neck pathology and the length of tire in the apparatus (Fig 30)

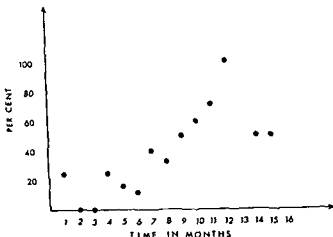


Figure 30 Plotted points to demonstrate the percentage of patients with radiologically abnormal cervical spines tending to increase as the length of time in the halo pelvic apparatus increases

The etiology of deformity

Patients with radiological changes in the cervical spine were classified according to the various etiologie as follows tuberculous kyphosis 47 per cent paralytic scoliosis 40 per cent idiopathic scoliosis 45 per cent congenital kyphoscoliosis 15 per cent and neurofibromatosis kyphoscoliosis 50 per cent

The barograph (Fig 31) confirms that there were more significance in the tuberculous kyphosis and paralytic scoliosis groups because of the larger samples available

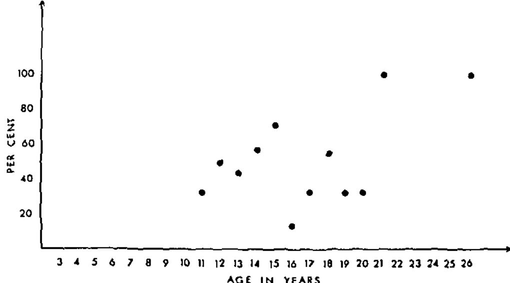


Figure 28 Plotted points to demonstrate the percentage of patients with abnormal cervical spines in the various age groups after treatment

Period of t… in the apparatu

The longer the patients were in the halo-pelvic apparatus the higher the observed incidence of radiological pathology in the cervical spine (Fig 29) In all groups of patients treated in the apparatus for longer than 7 months a significant number developed cervical spine changes

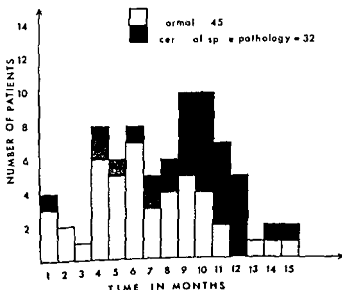


Figure 29 Barograph showing the relationship between radiologically abnormal cervical spines and the length of time in the halo pelvic apparatus

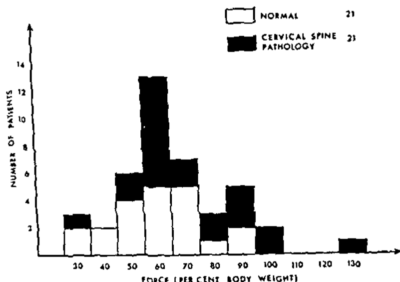


Figure 32 Barograph to demonstrate the relationship between radiologically abnormal cervical spines and the forces used in correction of the deformities

Neck pain is often experienced at some stage due to stretching If one examines the patient clinically whilst he has pain one can localise by palpation the segmental level at which the pain occurs The normal cervical lordo is disappears early and widening of the posterior synovial joints occurs more than in the intervertebral disc spaces which widen only slightly even with marked distraction hus the neck not only loses its lordosis but becomes slightly kyphotic

It should be emphasised that absence of pain in the cervical spine during gradual distraction does not necessarily mean that all is well Very slow rates of distraction are compatible with freedom from neck pain Extensive damage to the cervical spine due to over distraction can thus occur silently without either patient or surgeon being aware of it

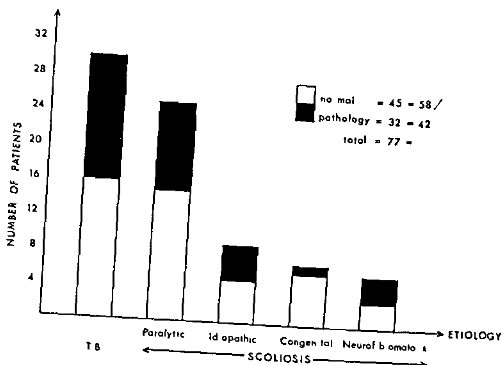


Figure 31 Barograph to demonstrate the incidence of radiologically abnormal cervical spines according to the etiology of the spinal deformity treated

Force measurements

Those who had force measurements and cervical spine radiographs available (42 patients) suggested that the higher the forces applied to the spine the greater the incidence of radiologically abnormal cervical spines The forces were recorded for this purpose as a percentage of the patient s body weight The critical level seemed to be 60 per cent of the patient s body weight beyond which there was a higher incidence of neck pathology

Lengthening in the cervical spine with distraction occurs mostly at the upper two levels they are the most mobile devoid as they are of protective intervertebral discs Case 71 a twelve year old male patient with a severe paralytic coliosis had lateral radiographs of the neck soon after treatment began and three months later (Figs 33 a and b) The amount of elongation which has occurred at the upper two levels with distraction is evident

The actual amount of cervical spine lengthening can only be judged with any accuracy from a lateral radiograph Clinically it is obvious that the neck has lengthened a good deal and the posterior arch of the axis initially not easily palpable because of the overlying muscle mass becomes readily felt through the stretched posterior soft tissues of the neck

There are numerous factors which determine how much the cervical spine itself will lengthen during spine di traction these include the patient s age the strength and volume of his neck musculature the rigidity of the spine deformity the effectiveness of a mobilising osteotomy if indicated and the rate and extent of distraction

The combination of a rigid deformity with rapid distraction is likely to produce an acute injury case 16 had a severe tuberculous kyphosis Following excision of the internal kyphos distraction commenced at a rate faster than usual resulting in acute neck pain A lateral radiograph several days later demonstrated an anterior avulsion of the ring apophysis of the inferior aspect of the second cervical vertebra (Fig 26 page 92) He subsequently developed spontaneous fusion of the upper cervical units

Simultaneous correction of the deformity and lengthening of the cervical spine

Four unselected patients with tuberculous kyphosis had serial lateral radiographs of the correcting kyphos and the lengthening cervical spine compared (Table 7)

Fixed points were selected on the limbs of the kyphos of the pre operative films and of those at the completion of treatment These were com ared with lateral cervical spine film before and at the end of distraction An estimate of the simultaneous amount of lengthening of the cervical spine could thus be made

There ere differences in each patient the best ratio was case 27 for one centimetre of measured neck lengthening there was 6 4 centi metres of lengthening at the internal kyphos The worst ratio was case 23 for 2 centimetres of neck lengthening 2 7 centimetres of lengthening at the internal kyphos was produced So many and varied

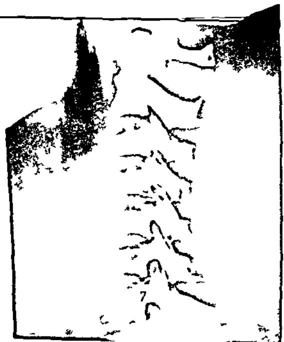


Figure 33 a Lateral radiograph soon after distraction commenced Note the distance between the dens and McGregor s line

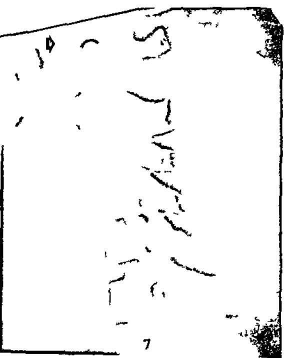


Figure 33 b Three months later there has been marked distraction of the cervical spine particularly at the upper two levels Note the increase in distance between McGregor s line and the top of the dens (arrow) Posterior joint spaces have widened more than the intervertebral disc spaces resulting in a slight kyphosis

Figures 33 (a) and (b) Case No 71 Lateral radiograph of cervical spine after fitting of the halo-pelvic apparatus and three months later after completion of distraction Patient had a severe collapsing scoliosis of 126° reduced to 63°

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Four unselected patients with tuberculous kyphosis had serial lateral radiographs of the correcting kyphos and the lengthening cervical spine compared (Table 7)

Fixed points were selected on the limbs of the kyphos of the pre operative films and of those at the completion of treatment These were compared with lateral cervical spine films before and at the end of distraction An estimate of the simultaneous amount of lengthening of the cervical spine could thus be made

There were differences in each patient the best ratio was case 27 for one centimetre of measured neck lengthening there was 6 4 centimetres of lengthening at the internal kyphos The worst ratio was case 23 for 2 centimetres of neck lengthening 2 7 centimetres of lengthening at the internal kyphos was produced So many and varied

are the factors involved that one can only rely finally on regular radiographs and clinical judgements of the patient s reponse to treatment

TABLE 7

Case number	Lengthening at internal kyphosis (in centimetres)	Simultaneous lengthening of cervical spine (in centimetres)
	(Measurements from lateral radiographs)	
13	6 0	3 0
21	2 7	1 0
23	2 7	2 0
27	6 4	1 0

Corresponding simultaneous lengthening at the internal kyphos and cervical spine measured from lateral radiographs at the end of distraction

Continuing lengthening without actual distraction

A significant lengthening of the cervical spine can often be measured in patients held in the apparatus who are no longer undergoing active distraction If one measures the length of the cervical spine from a radiograph after the last operation and before the removal of the apparatus this lengthening may be as much as 5 millimetres This is more likely when several months have elapsed between the last operation and the removal of the apparatus and in patients with paralytic neck muscles Although one is not actively lengthening the spine it is continually deforming (or creeping) with the passage of time (6) A typical example of this phenomenon is case 18 a patient with a severe lumbar tuberculous kyphosis who was corrected by staged procedures and then remained in the apparatus for a further 8 months On comparing identical lateral radiographs of the neck at the time of fusion and at the time of removal of the apparatus 8 months later there had been an increase in length of 0 5 centimetres in the cervical spine (Figs 34 a and b)

There are two separate mechanisms which singly or together produce the pathological changes in the cervical spine They are 1) deformity



Fiqı e 34 a Taken at the completior of surrery



Figure 34 b Taken eight months later when the patient was still in the apparatus but without any distraction Note the increase in width at the atlanto occipital joint without a tive distraction having taken pla e

Figures 34 (a) and (b) Case 18 Lateral radiograph of upper cervical spine

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There are two separate mechanisms which singly or together produce the pathological changes in the cervical spine They are 1) deformity

occurs here the greatest residual disability will be due to loss of motion at these levels

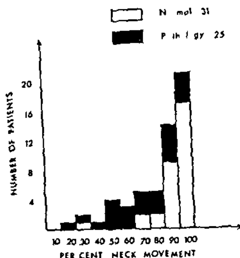


Figure 35 Barograph to demonstrate the relationship between radiologically abnormal cervical spines and clinical motion

INTESTINAL OBSTRUCTION

Three patients developed an acute duodenal obstruction of the type *recently described by Evarts et al (21) They all had marked* compensatory lumbar lordoses As in nerve injuries early diagnosis is important since a delay in diagnosis affects the prognosis considerably

Occasionally small bowel obstruction may occur after the patient has had the extension bars fitted The constricting band can be removed from the compressed anterior duodenal wall by adjusting the extension bars th s *reducing some of the lordosis*

Diagnosis was promptly made when the patients started vomiting after the fitting of the extension bars A plain erect antero posterior radiograph of the abdomen showed distension of the stomach and the *first half of the duodenum* To confirm the level of the obstruction a small volume of soluble gastrografin was used this is unneces ary in the established case as the gas shadows in the radiograph will

(distraction) both acute and chronic and 2) prolonged immobilisation Acute over distraction in association with a rigid curve is highly dangerous to the cervical spine (Fig 26 page 92) but more especially to the integrity of the spinal cord and its blood supply Chronic over-distraction accounts for the avascular necrosis of the dens (60) This is due to the proximal pole of that vertebra being pulled away from its blood supply It was significantly more common in patients with marked lengthening of the neck (10 out of 13 patients with this lesion had tuberculous kyphosis)

A detailed account of the complication of avascular necrosis of the dens has been made recently (60) When the lateral radiograph of the cervical spine was examined with the patient in the halo-pelvic apparatus and the distance from McGregor s line to the top of the dens was greater than the vertical height of the posterior aspect of the third cervical vertebra there was a high risk of avascular necrosis of the proximal pole of the dens occurring

Prolonged immobilisation together with persistent deformity of the posterior joints produces degenerative joint changes (20) Pannus grows into the joint across the articular cartilage causing interference with its nutrition and its early degeneration (55)

The available evidence suggests that (a) acute distraction (b) excessive lengthening and (c) prolonged immobilisation singly or in combination produce deleterious effects in the cervical spine

Clinical evaluation

Detailed measurements of neck motion were made in 56 unselected patients at least one year after treatment was complete Nearly half (26 patients) had practically normal neck movements Those with radiologically abnormal cervical spines had a significantly higher incidence of reduced motion (Fig 35) It has appeared that with time and use neck movements continue to improve for up to 12 months after treatment

The average patient several years after treatment had a painfree neck with loss of up to 30 degrees of rotation As most rotation occurs in the upper cervical units because the greatest distraction

Inf ction

Bone graft was taken from the iliac crest above the pelvic pins in many patients In some of them the donor wound was slower in healing but there was no significant problem There was one posterior wound infection following the use of iliac crest bone but it settled with irrigation and drainage If this bone is used however prophylactic antibiotics are necessary as the graft is potentially infected

Cont ruing p nal rowth n the appara us

In the presence of an intact posterior fusion mass and continuing growth of the vertebral bodies an increase ir the deformity was observed in three patierts despite being held in the apparatus Ca e No 52 va a nire year old male patient with a collapsing paralytic scoliosis of 112 degrees (Fig 36 a) which was corrected by halo pelvic distraction to 21 degrees (Fig 36 b) Although he was maintained in the apparatus for a further 12 months after surgery the curve when the apparatus was removed measured 47 degrees an exploration of the fusion mass six months after fusion having previously confirmed that it was solid (Figs 36 c and d)

In he presence of marked rotational deformity present in many of these patie ts growth from the vertebral bodie would actually increase the length of the curve on the convex ide whilst the concave or fused part of the spine is being b nt by thi continuing convex growth The fusion mass is thus acting as if it were an unsegmented bar

The other explanation in this situation is that because of the visco elastic propertie of tissues gradual sagging of the fused spine and continuing lengthening of the cervical spine takes place even though no active distraction is taking place

he practical points raised here are 1) Internal fixation hould be u ed with scoliotic deformities when possible 2) The period of time in traction hould be kept to a practical minimal period compatible with the patient s general physical state particularly his respi ratory function

usually become conspicuous by their absence beyond the end part of the duodenum

OSTEOPOROSIS

Osteoporosis is an inevitable accompaniment of the immobilisation produced by the halo-pelvic apparatus (Fig 25, page 92) (4) Radiologically it is evident in all bony tissues between the skull and the pelvic pins Radiographs of the pelvis taken several months after completion of treatment with halo-pelvic distraction confirm that bone lost above the pelvic pins has not been fully replaced

The clinical problems encountered with osteoporosis have been difficulties with internal fixation notably seating the hooks for the Harrington rod the vertebral body screws in Dwyer instrumentation and the pelvic pin fixation in paralytic patients

MISCELLANEOUS

Deaths

There were four deaths in the series Three patients died within five days of anterior spinal surgery two within twenty four hours of the operation One patient died within twenty-four hours of multiple posterior spinal osteotomies All had severe respiratory insufficiency and a moderate to severe degree of blood loss at the time of surgery The causes of death were paralytic ileus and pneumonia in one patient acute respiratory failure and blood loss in one patient and acute respiratory failure in two patients

Pressure sore over the kyphos or rib hump

It is surprising how large an area of skin is made temporarily anaesthetic by the combination of posterior vertical and oblique skin incisions These patients with double skin incisions must be watched carefully particularly if the back winder is being used This requires releasing every hour and the skin checked regularly for signs of redness or early breakdown

Infection

Bone graft was taken from the iliac crest above the pelvic pins in many patients in some of them the donor wound was slower in healing but there was no significant problem There was one posterior wound infection following the use of iliac crest bone but it settled with irrigation and drainage If this bone is used however prophylactic antibiotics are necessary as the graft is potentially infected

Continuing spinal growth in the apparatus

In the presence of an intact posterior fusion mass and continuing growth of the vertebral bodies an increase in the deformity was observed in three patients despite being held in the apparatus Case No 52 was a nine year old male patient with a collapsing paralytic scoliosis of 112 degrees (Fig 36 a) which was corrected by halo pelvic distraction to 21 degrees (Fig 36 b) Although he was maintained in the apparatus for a further 12 months after surgery the curve when the apparatus was removed measured 47 degrees an exploration of the fusion mass six months after fusion having previously confirmed that it was solid (Figs 36 c and d)

In the presence of marked rotational deformity present in many of these patients growth from the vertebral bodies would actually increase the length of the curve on the convex side whilst the concave or fused part of the spine is being bent by this continuing convex growth The fusion mass is thus acting as if it were an unsegmented bar

The other explanation in this situation is that because of the visco elastic properties of tissues gradual sagging of the fused spine and continuing lengthening of the cervical spine takes place even though no active distraction is taking place

The practical points raised here are 1) Internal fixation should be used with scoliotic deformities when possible 2) The period of time in traction should be kept to a practical minimal period compatible with the patient s general physical state particularly his respiratory function



Figure 36 a Antero posterior radiograph with the patient seated Note *extent of pelvic* obliquity

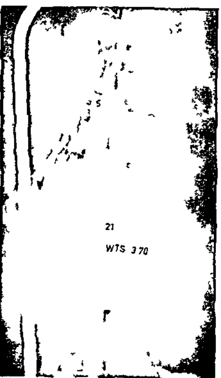


Figure 36 b Following gradual correction extensive *posterior spinal fusion was performed from* the first thoracic vertebra to the sacrum curve then measured 21°

Figures 36 (a) (b) (c) and (d) Case 52 A *nine-year-old male patient with* severe collapsing paralytic scoliosis measuring 112° no walking potential because of severe four-limb involvement



Figure 36 c *Thirteen months* later curve has deteriorated to 47^0 despite being held during this period of time in the halo pelvic apparatus The likeliest explana tion for this phenomenon is continuing growth in the vertebral bodies (See text)

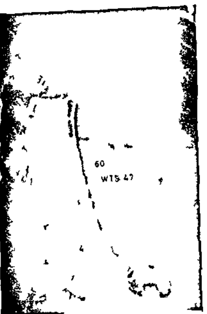


Figure 36 d Antero posterior radiograph of same patient fou *years after spinal fusion* Further loss of corre tion in the fused spine the curve now measures 60^0 Note the recurrence of the pelvic obliquity Internal fixation was not possible because of soft bone and the thinness of over lying soft tissues

Psychological disturbances

These were minimal and in fact non-existent when the method of treatment was explained fully to the parents and to the patient. The recommended approach is to introduce a patient under treatment in the halo pelvic apparatus to the parents and the patient and permit them to talk the matter over. It is helpful to demonstrate the results before and after with radiographs and rarely will the parents of a child or the patient himself not consent to corrective surgery.

One constant feature has been the dramatic improvement in the psychological attitude of the patient when he has seen the correction of his spinal deformity being obtained. Supportive psychological therapy is an all important part of the overall technique with these patients and it requires the skill and gentle care of all physicians and paramedical personnel involved with the patient.

DISCUSSION

When reviewing these results they must be assessed bearing in mind that 21 per cent of the patients had cord compression or frank paraplegia at the onset of treatment (tuberculous kyphosis 16 patient, congenital 2 and neurofibromatosis deformities 3 patients). In addition more than fifty per cent of all patients had significant respiratory impairment for which two required elective tracheostomy (tuberculous kyphosis).

Thus a large number of these patients had, in addition to severe spinal deformities, associated poor lung function and a compromised and severely threatened spinal cord.

The actual average corrections achieved were tuberculous kyphosis 31 per cent, paralytic scoliosis 51 per cent, idiopathic scoliosis 42 per cent, congenital kyphoscoliosis 26 per cent, neurofibromatosis kyphoscoliosis 43 per cent and the salvage group (osteotomies of previous posterior fusion masses) 40 per cent.

The correction of the tuberculous kyphosis series is better than it appears the average apex of the kyphos was at the ninth thoracic vertebra (Fig 11 page 45) and a natural kyphos of twenty to forty degrees exists in this region of the spine

The average co rec ion of the patients with idiopathic scoliosis (42 per cen) was not as good as expected Significant derotation of the major curve do-s occur with the halo pelvic apparatus when it is used in c njunction with the back winder (Fig 4 page 18) However whilst the average cu ve was moderately severe (82 degrees) it would seem that th halo pelvi apparatus in idiopathic scoliosis should be re erved for p tients with rigid curves over 100 degrees ideally with associated re piratory insufficiency making longitudinal traction in bed or on a frame inwise

The complications of greatest concern were pathological changes in the cervical spine mainly degenerative changes in the posterior joints avascular necrosis of the dens and chronic atlanto axial subluxation Most of the other problems encountered were temporary or avoidable pelvic pin tra t infection was common but was usually managed without difficulty Th re were no instances of osteomyelitis of the ilium nor of a case wher the infection necessitated a change in the patient s management oth r than the three patients with pelvic obliquity who required early removal of the apparatus The problem and the difficulties and dangers with pelvic obliquity for the pelvic pins have been stressed The torn peritoneum in one patient has been emphasi ed in order to avoid its recurrence

The principle in using the halo pelvic apparatu is to follow a planned technique to observe the patient closely to organise a team approach for the patients management and to anticipate problems so that they are dealt with early and effectively

SU MARY A D CO CLUSIO S

One hundred and four patients with severe spinal deformities commenced treatment in the halo pelvic apparatus There were four post operative deaths the etiology of the spinal deformities was tuberculous kyphosis 42 patients paralytic scoliosis 31 patients idiopathic

scoliosis 15 patients congenital kyphoscoliosis 10 patients, and neurofibromatosis kyphoscoliosis 6 patients The average time in the apparatus was 7 5 months

Eleven patients with paralytic scoliosis had associated pelvic obliquity Twenty one per cent of patients had cord compression or frank paraplegia at the commencement of treatment Respiratory insufficiency was a common accompaniment of the spinal deformity especially in those patients with tuberculous kyphosis and paralytic scoliosis

The average corrections of the deformities were as follows tuberculous kyphosis 31 per cent paralytic scoliosis 51 per cent idiopathic scoliosis 42 per cent congenital kyphoscoliosis 26 per cent and neurofibromatosis kyphoscoliosis 43 per cent An analysis of a salvage group previously failed posterior fusions for scoliosis leading osteotomies distraction and fusion revealed a correction of 40 per cent

Many complications due to distraction were easily remedied but the more serious were temporary spasticity in the lower limbs 3 per cent temporary brachial plexus paresis 3 per cent and cranial nerve palsies 7 per cent

Of seventy-seven patients who had cervical spine radiographs taken thirty-two had radiologically abnormal cervical spines The most common neck complication was degenerative changes in the posterior synovial joints These appeared more commonly in the older patients with excessive distraction and with prolonged time in distraction

The halo-pelvic apparatus is an effective instrument for the correction of severe deformities of the spine particularly for patients with poor respiratory function and cord compression or frank paraplegia Its use requires judgement and team work close observation and attention to detail in view of the complications encountered

PART III

THE HALO PELVIC APPARATUS AN ANALYSIS OF ITS STABILISING EFFECT AND OF THE FORCES BEING APPLIED THROUGH THE SPINE WITH ITS USE

by

John Patrick O Brien
Gosta Elfstrom
Alf Nachemson

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INTRODUCTION

The aims of this project are (1) to analyse the stabilising effect of the halo pelvic apparatus on the deformed spine and (2) to determine what proportion of the tension developed by halo pelvic distraction is actually transmitted to the spine itself

Halo pelvic distraction is becoming more widely known as a method for gradually correcting severe spinal deformities Complications due to over distraction have been reported notably injuries to the cervical spine paraplegia and temporary nerve lesions (34 48)

Considering these complications and the ignorance of the corrective forces being applied to the spine a spring system on each of the four extension bars was developed in 1970 in conjunction with Clark and Kesterton of the Department of Mechanical Engineering at Hong Kong University (5) This gave a measure of the forces being used during treatment of the patients the distraction force were readily calculated from the extent of compression of the springs but there was no indication of what proportion of the measured forces was actually transmitted to the spine itself

In April 1971 Nachemson and Elfstrom reported their results of intravita wireless telemetry of forces in four patients with idiopathic scoliosis using a modified Harrington rod (41) The information obtained from this work permitted a more rational approach to the post operative management of the scoliosis patient (17 18)

If this special Harrington rod was used in patients in conjunction with the halo pelvic apparatus the inherent stability of the latter could be assessed and the external forces applied with lengthening of the extension bars and measured on the springs could be checked against the internal measuring rod to give an assessment of the tension actually transmitted to the spine (Fig 37) This work was carried out at The Duchess of Kent Children s Orthopaedic Hospital Hong Kong in October November 1972 (19)

CLINICAL MATERIAL (Table 8)

There were four patients with severe paralytic scoliosis requiring preliminary traction before extensive spinal fusion with Harrington rodding Three of the e were males and one female with ages ranging from 12 5 to 16 5 years Two of the patients curves were thoraco lumbar and two were thoracic in type all four were convex to the right side The curves varied in extent from 95 to 145 degrees (average 112 degrees) The major curves involved from five to nine vertebrae the angle of kyphosis ranged from 63 to 142 degrees

OUTLINE OF TREATMENT

The following steps were taken 1) fitting of the halo pelvic appa ratus 2) insertion of the special Harrington rod 3) removal of the rod standard posterior fusion and fitting of a standard Harrington ro 4) removal of the halo pelvic apparatus approximately six weeks later

Preliminary investigations were the routine tests prescribed for all patients with spinal deformities and these included full radiographs and respiratory function tests

Details of treatment

1 The skull halo pelvic pins and hoop were fitted in exactly the same manner as has been previously described (48) Fitting the extension bars several days later with the patient eated and comfortably suspended by the kull halo is easier both for the surgeon and for the patient

2 The special Harrington rods were inserted by the method previously d scribed 41) Normally at operation the two anterior bars are left in position on the apparatus removing only the posterior bars to allow access to the spine In these patients all four bars were removed so that the forces could be evaluated whilst the bars were being applied The operations were done with the patient prone on the Relton Hall frame (53)

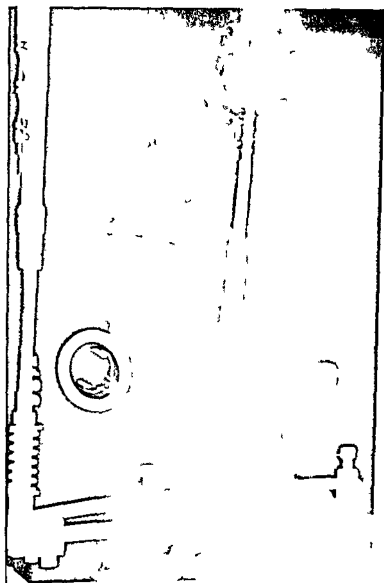


Figure 37 Patient No 1 Antero posterior radiograph of patient with paralytic scoliosis Note the extension bar of the halo pelvic apparatus with the compression spring at its base in addition to the telemetry rod with the coil and transmitter

A midline vertical posterior incision and the standard subperiosteal exposure of the concave bony elements was made The upper and lower Harrington hooks were inserted in the routine manner The special rod was then placed in position and the coil and transmitter put into an adjacent subcutaneous pocket A force gauging distractor (40) was used to distract the rod Initial readings were taken from the special rod at this stage and continued during the operation Over the next even to ten days three ets of readings were taker at different times (a) from the halo pelvic springs (b) from the special Harrington rod and (c) from a spring balance suspending the halo with the extension bar removed

3 At re operation approximately two week later the telemetry rod was replaced with a standard Harrington rod and further distraction attempted The convex side of the curve was also dissected free of soft tis ue and a routine po terior fusion done A two stage correc tion was routine at the Department of Orthopaedic Surgery I in Goteborg (18) Supplementary anterior fusions were done in two pat ent (Nos 1 and 3) because of the kyphotic component in their deformities

4 The halo pelvic apparatus was removed approximately six weeks after th pine fusion and full length body cast fitted to the patients

RE ULTS

A Du ing the ope ation
B At the end of operation
C Lifting the patient from the operation table to the bed

A During the ope ation (Table 9)

When the concave aspect of the scoliosis had been expo ed and the upper and lower hooks placed in position the modified Harrington rod was then onnected up and the manual force gauging distractor used to extend the rod The di traction forces varied from 15 to 40 kp Patient No 2 in whom the 15 kp reading wa made had low rea lings throughout because of the osteoporotic bone which was unable to hold the upper hook Con equently a firmer purchase for the seating of

TABLE 8

Case number	Age/Sex	Body weight* (pre op) (kg)	Pre operative details of major curve all convex to right side: Extent *	Pre operative details of major curve all convex to right side: Angle of coliosis (Cobb) (degrees)	Post operative curve mea urement (AP film) (degrees)	Correction (per cent)	Period of time between fitting of H P T and insertion of special Harrington rod (days)	Force on spine measured from springs before surgery (patient standing) (kp)
1	13 5/M	46	T11 L3 (5)	105	54	48	27	14 2
2	12 5/M	26	T4 T12 (9)	105	85	19	29	7 7
3	16 5/M	32	T11 L3 (5)	145	60	51	29	16 5
4	16/F	28	T5 T12 (8)	95	46	51	2	2 2

Body weight may change significantly if patient is in the halo pelvic apparatus for a prolonged period

~ber of vertebrae in major curve

the hook was obtained by u ing acrylic ce ent

The first readings taken from the telemetry rod ranged from 7 to 20 kp (column 3) In general terms the force in the rod was approximately 50 per cent of those measured with the manual distractor However in patient No 3 a gross kyphotic element (142 degrees) produced a large element of friction between the rod and the hoo s creating readings on the distractor which were higher than would otherwise have been anticipated

The differences in these two sets of readings (manual distractor and telemetry rod) might be due to the fact that the man al di tractor measures total force of distraction including friction between hook and rod whereas the telemetry rod registers only the axial component of hat force It will always therefore have a lower reading than the manual distractor

The force in the special rod were again measured at the end of the operation By this time the stability of the two hooks had been checked and both the transmitter and the power transfer coil had been placed in pockets developed between the subcutaneous tissue and the dorso lumbar fascia The wound was closed in layers and continuous su tion drainage was used Readings at this stage varied from 6 to 11 kp (Table 9 column 4) an average of 60 minutes having elapsed between the first and the second readings from the rods

The progressive decline of forces registered in the od is evident notably in patient No 4 where over this 60 minute period the rod readings fell from 18 to 7 kp The average initial eading f n the Harrington rod was 14 5 p and the average reading after 60 minutes at the end of the operation was 7 5 kp In bro d terms approximately 50 per cent of the force through the od had vanished at the end of the operation similar to he results previously reported (18 41) There is an inevitable decline in forces due to the visco elasticity of the stretched tissues later readings will always be lower than the initial ones

TABLE 9

Demonstration of the forces measured with the manual distractor and the special Harrington rod during operation in four patients. Measurements also obtained both during reapplication of the four extension bars to the halo pelvic apparatus and during lifting and turning the patients at completion of the operation

Case number	Maximum force used during operation		Forces in the rod when H P T applied at end of operation			
	Manual distractor (kp)	Special Harrington rod (kp)	*Patient prone and* before bars fitted (approx 60 min later) (kp)	*Anterior bars* fitted (kp)	*Posterior bars* fitted (kp)	*Lifting and turning* maximum force (kp)
1	40	20	11	(i) 10 (prone)	(ii)* 11 (prone)	14 (+3)
2	15	7	5	(ii) 2 (supine)	(i) 3 (prone)	3 (+1)
3	40	13	7	(ii) 6 (supine)	(i) 6 (prone)	9 (+3)
	30	19	7	(i) 6 (prone)	(ii) 3 (supine)	Reading not taken

* (i) and (ii) signifies the sequence in which the bars were placed in position between the skull halo and pelvic hoop

Figures measured for the special rod are usually about half of those measured with the force gauging distractor, adjacent column. The discrepancy here was due to a gross kyphotic element (in this patient 142 degrees) which tended to bend the rod and thus produced a large element of friction

TABLE 10

A demonstration of the inherent stability of the halo pelvic apparatus Comparison of measurements during and immediately following surgery (in kiloponds)

<u>Group A</u> Non halo pelvic group First four patients in whom special rod was used

<u>Group B</u> Halo pelvic group Four patients in this series

Group	Case No	Maximal reading during distraction (manual distractor) (kp)	Reading in special rod after 60 minutes (kp)	Reading in special rod after all four halo pelvic bars are applied (kp)	Maximal reading in special rod lifting and turning (kp)	Change in reading in special rod (kp)
A	1	42	31		43	+12
	2	25	18		32	+14
	3	21	12		16	+4
	4	20	14		23	+9
B	1	40	11	11	14	+3
	2	15	5	2	3	+1
	3	40	7	6	9	+3
	4	30	7	3		-

Reference Elfstrom & Nachemson Clin Orth 93 158 172 June 1973

B End of operation - reapplying the extension bars (Table 9)

The four extension bars were reapplied during which time readings of the internal force were taken The anterior extension bars were re-applied first in patients No 1 and No 4 and the posterior bars first in patients No 2 and No 3 The patient in each case was prone for the fitting of the first bars in patient No 1 the prone position was maintained but the other three patients were turned to the supine position on the table before the second set of bars was reattached to the halo and pelvic hoop The length of the bars was not altered in any way from their pre operative length

During the refitting of the extension bars seven of the eight readings were less than those taken before the bars were attached In patient No 4 a significant reduction in the force on the rod (from 6 to 3 kp) was recorded with the fitting of the posterior bars in the supine position with the anterior bars already in place There are two explanations for this The refitting of the bars tends to unload the rod slightly and with the progress of time there is still further decline in the forces on the rod

C Lifting the patient from the operating table to the bed (Table 9)

The patient was lifted from the operating table and placed on his ward bed Patient No 1 needed to be turned to the supine position and then placed on the bed the other patients were already supine on the operating table the spinal frame having previously been removed Readings were taken whilst the patients were transferred from the table to their beds (except for patient No 4 where readings were not taken at this stage)

All three patients measured registered an increase in forces on the rod when compared with the last readings taken during the fitting of the second pair of extens on bars (Table 9 columns 5 and 6 Fatients No 1 and No 3 showed an increase of 3 kp force in the rod patient No 2 an increase of 1 kp There was little influence on the rod in the patients during refitting of the extension bars nor did there seem to be any consistent difference in the forces of the patients who had the anterior bars fitted before the posterior ones or those who had the bars fitted in a prone or supine position It is important however that this fitting be done carefully

TABLE 11

M a c a d th a q f e meas ed w th sp ci l od (k lopo ds)

	Act v ty perfo med	GROUP A NON HALO PELVIC		GROUP B HALO PELVIC	
		Mea	Range	Mean	Range
Day of ope ation	L fting and t ni g f om ope at g table to bed	5	0 to 14	2	1 to 3
	Cough ng du ng r cove y (f st fo ho s)	3	0 to 6	2	1 to 3
	V mit j di ing recove y	30 (one patient)		4 (patient No 4)	
	Po it ve p essure b eathing (Bi d sp rato)	1	0 to 2	1	0 5 to 1 5
Day 2 to 3 post opera tively	Bicycle exercises in bed	2	0 to 5	No inc ease	No increase
	A m exe cises	7	5 to 10	No increase	No increase
	Turning in bed to convex side	3	2 to 4	3	1 to 7
	Turning in bed to concave side	1	0 to 2	0	0 to 1

Cf patient L K J Bone Joint Surg (A) 53A 445 465 April 1971

The stability of the apparatus is apparent when comparing this group of patients with a previous group who were not in the halo-pelvic apparatus (41) They had the telemetry rod applied and measurements were taken when the patients were lifted from the table to the bed

Table 10 shows two such groups, a non halo-pelvic and a halo-pelvic" group In the 'non halo-pelvic group (Group A) the changes in the rod forces during lifting and turning varied from an increase of 4 to an increase of 14 kp in three of these four patients the increase at this stage exceeded the highest forces registered during the operation itself when the rod was first inserted With the stability of the halo-pelvic apparatus in the three patients where readings were taken (Group B) the maximum increase in the rod force during lifting and turning varied from 1 to 3 kp

D Readings in the rod after surgery and during the first three post-operative days (Table 11)

Day of operation

Coughing or straining during recovery from anaesthesia produced a mean increase of 2 kp in the rod (range 1 to 3 kp) One patient vomited during recovery (patient No 4) and an increase of 4 kp was recorded These figures are more meaningful when compared with the mean increase and range in forces measured with the special rod in the group of patients who were not in the halo pelvic apparatus (Table 11) This non halo-pelvic group had a mean increa e of 5 kp (range 0 to 14 kp) during lifting and turning from the operating table to the bed

In the recovery phase after surgery the non halo pelvic group had a mean increase of 3 kp recorded in the rod (range 0 to 6 kp) In one patient (41) an increase of 30 kp was observed when vomiting occurred during the post-operative period

Comparing these two groups of patients with and without the support of the halo pelvic apparatus demonstrates the stability and protec tion for the implanted rod provided by the halo pelvic apparatus The greatest difference was recorded in the two patients who vomited during recovery the patient without external support had an increase of 30 kp recorded in the rod as opposed to the patient in the halo

TABLE II

M a a f th a q fo e me d w th p al od (k l po d)

	Act ty pe fo med	GROUP A NON HALO PELVIC		GROUP B HALO PELVIC	
		Mean	Ra ge	Mean	Range
Day of opc ation	L ft ng and t i g f om ope at ng table to bed	5	0 to 14	2	1 to 3
	Coughing du i g recove y (fi st fou hours)	3	0 to 6	2	1 to 3
	Vo it n i d n i ecove y	30 (o e patient)		4 (patient No 4)	
	Posit ve p essure b eathing (Bi d spi ato)	1	0 to 2	1	0 5 to 1 5
Day 2 to 3 post ope a tively	Bicycle exercises in bed	2	0 to 5	No inc ease	No increase
	Arm exercises	7	5 to 10	No increase	No increase
	Turning in bed to convex side	3	2 to 4	3	1 to 7
	Turning in bed to concave side	1	0 to 2	0	0 to +1

Cf patient L k J Bone Joint Surg (A) 53A 445 465 April 1971

pelvic apparatus in whom an increase of only 4 kp was measured

Day 2 to 3 post-operative

On the second or third day after surgery the patients used the Bird respirator for positive pressure breathing In the halo pelvic group mean increases of 1 kp were recorded (range 0 5 to 1 5 kp) When compared with group A (non halo-pelvic) there was little difference, for, in this group the mean increase was the same (1 kp) and the range of increase similar (0 to 2 kp) It would seem that using the respirator places little stress on the spine

On the third day after surgery the following activities were performed by the patients

1 Cycling exercises in bed
2 Arm exercises
3 Turning in bed to the convex side of the major curve
4 Turning in bed to the concave side of the major curve

1 Cycling exercises in bed

No increases were recorded in the halo pelvic patient whereas in group A (non halo-pelvic) mean increases of 2 kp (range 0 to 5 kp) were recorded with this manoeuvre

2 Arm exercise

The patients were encouraged to lift weights with both hands and also to exercise against the resistance of a spring type chest expander In the halo pelvic group no increase in forces was observed In the non halo pelvic group mean increases of 7 kp were measured during the same exercise (range 5 to 10 kp)

The stability provided by the halo pelvic apparatus is probably best demonstrated in this particular series of exercises where no increase in forces on the rod were recorded

3 and 4 Turning in bed to the convex and concave side of the major curve

The patients were assisted to turn in bed so that the convex part of

tre instrurented curve was lowermost and readings were taken during this chan,e in position There was a mean increase of 3 kp in the halo pelvic group (range 1 to 7 kp)

They w re then assisted back to the supine position and turned to the opposite side o that the corcave side of the deformity was facing downwards The mean increase during this manoeuvre was zero (range 0 to 1 kp)

Similar increa es were observed in both groups of patients namely a larger in rea in force on the rod when the patient was turned to the convex sid (Table 4)

E An assessment of the tension transmitted to the spine with the halo pelvic apparatus

Two separate investigations were carried out Firstly the springs at the base of th extension bars were measured with a vernier caliper in the routine manner and the forces calculated as described in Part I This wa done with the patient seated All four extension bars were then lengthened by increments of 2 millimetres and after each ex ens on the prings were measured again and readings were taken from the special Harrington rod

The lengthening was done over approximately 20 to 30 minutes and in each patient 8 to 10 millimetres of lengthening of the bars was tolerated without discomfort The external and internal force readings at various increases in spine length were taken and the respective points were plotted

S ondly a pring balance with cords and small hooks was connected to the skull halo and upward traction through the halo was applied approx mately qual to that measured on the springs The four exten sion bars were then removed The force in the spring balance was then altered gradually in stages and at each stage readings were taken from the spring balance and simultaneously from the internal rod The e points were similarly plotted

DISCUSSION

As would be expected there is a direct relationship within certain limits between the external force applied either by the spring balance or the halo pelvic apparatus and the internal forces on the spine measured simultaneously on the special rod One should not draw definite conclusions from these curves because of the multitude of variables such as age, body weight and height site of deformity pattern of muscular imbalance to mention only some of them The measuring systems do appear to be consistent although the differences in each patient are vast

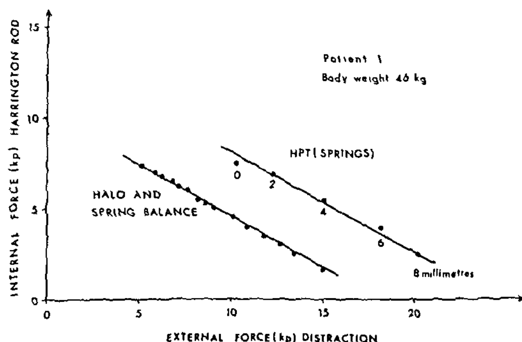


Figure 38 Patient No 1 Plotted curves of internal force against external force measurements The external force systems included
<u>left curve</u> the skull halo with the spring balance <u>suspending</u> it with the extension bars removed
<u>right curve</u> the springs compressed at the bases of the <u>four extension</u> bars

In patient No 1 with an internal force of 5 kp (Fig 38) the halo and spring balance registers 9 kp and the halo pelvic springs 16 kp a difference of 7 kp between the two external readings for the same internal measurement The difference can be explained by friction in the halo pelvic spring measuring system and the error of the force readings of this system Furthermore patient No 1 was a tall boy on whom long extension bars had to be used This creates difficul ... in

the alignment of the four bars and there is a greater risk of friction in the system The sprirg balance applie its force directly on the halo axially on the spine and without either friction or bending moments

In patient o 4 (Fig 39) for the same internal reading (5 kp) the halo pelvic springs register 6 kp and the spring balance springs 7 5 kp Note in this patient that the plotted curve have changed their po i tion relative to one another the halo pelvic spring curve has the lo er offset In this patient a small female the bars were easy to align and no friction was noted The difference between the two curves can be explained by the error in spring mea urements

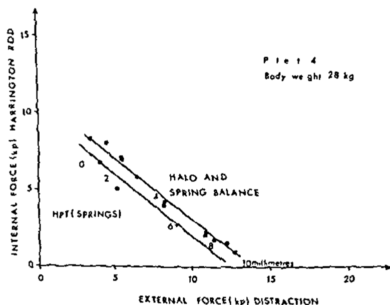


Figure 39 Patient no 4 Plotted curves of internal force against external force measurements The external forre system included
left curve the springs compressed at the bases of the four extension bars
right curve the kull halo with the spring balance suspending it with the extension bars removed

Perhaps the wider scatter of the points in patient No 4 (Fig 39) when compared with patient No 1 (Fig 38) is due to the fact that the external readings extend over a range from 3 to 12 5 kp In patient lo 1 they vary from 5 to 20 kp It is likely that the

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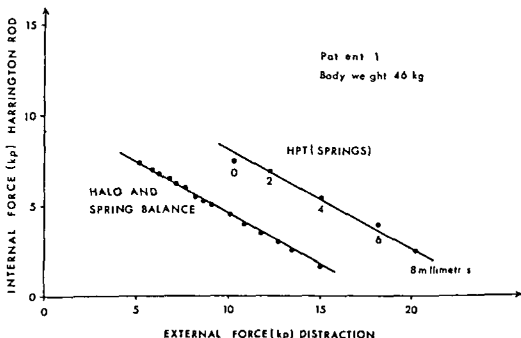


Figure 38 Patient No 1 Plotted curves of internal force against external force measurements The external force systems included
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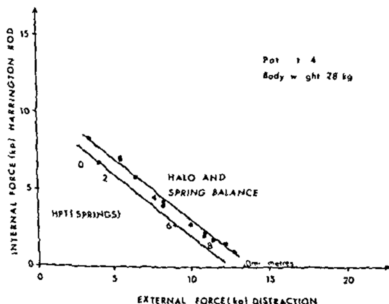


Figure 39 Patient No 4 Plotted curves of internal force against external force measurements The external force systems included
left curve the springs compressed at the bases of the four extension bars
right curve the skull halo with the spring balance suspending it with the extension bars removed

Perhap tre wider scatter of the points in patient No 4 (Fig 39) when compared with patient No 1 (Fig 38) is due to the fact that the external readings extend over a range from 3 to 12 5 kp In No 1 they vary from 5 to 20 kp It is likely that the

springs will tend to be more accurate once their initial slack has been taken up

For an increase in length of 8 millimetres for patient No 1 (Fig 38) the halo-pelvic springs registered an increase of 10 kp (from 10 to 20 kp) In patient No 4 (Fig 39) for the same increase in length the external force increase was 7 8 kp (from 3 2 to 11 kp)

In the plotted curves the offsets are different in both patients for both external measuring systems when plotted against the force on the rod (The offset is found by extending the curves to where they meet the vertical axis i e the external force is zero) In patient No 1, the offset is 10 kp for the halo and spring balance and 14 kp for the halo-pelvic springs For patient No 4 the offset for the halo pelvic springs is 10 kp, and for the halo and spring balance it is 11 kp but again the slopes for each patient are the same

In patient No 1 the internal force is equal to 60 per cent of the externally applied distractive force In patient No 4 the internal force reduction was equal to 80 per cent In other words for these two patients over this range of forces and under these specific circumstances 60 and 80 per cent of change in the external force respectively appears as a change in the internal force The linear relationship between the force (stress) and deformation (strain) demonstrates the elastic properties of tissue (22)

In Fig 40 (halo-pelvic springs and internal readings) the curves for both patients are linear the measured points fall nearly along straight lines and these lines fairly closely approximate equal slopes

In Fig 41 (halo and spring balance and internal readings) the curves are more or less linear and the two slopes are reasonably close to each other considering the differences between the patients ages heights body weights and their site and extent of deformity

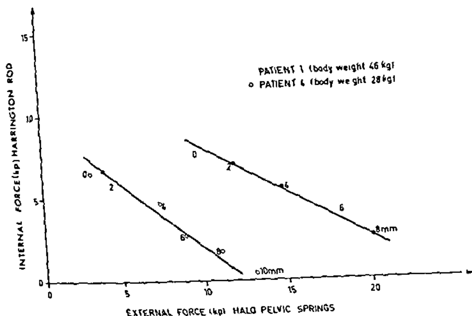


Figure 40 Plotted curves of the external force measurements for both patients (halo pelvic springs) and the internal force measurements (telemetry rod)

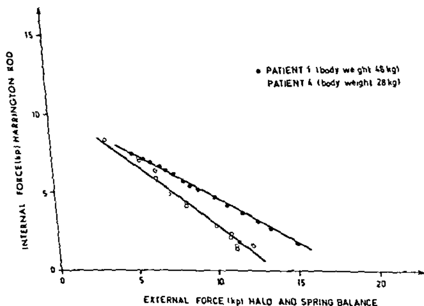


Figure 41 Plotted curves of the external force measurements for bot patients (the halo and spring balance system) against the internal force measurements (telemetry rod)

SUMMARY AND CONCLUSIONS

Four patients with severe paralytic scoliosis requiring preliminary pre operative halo-pelvic traction had a specially designed telemetry rod inserted during treatment and over the next 10 to 14 days measurements were taken from the telemetry rods and from the compressed springs at the base of the extension bars as well as from a pring balance suspending the skull halo with the extension bars removed

Readings from the telemetry rod were taken from the time of its insertion at operation and an early decline in forces on the rod was observed Replacing the extension bars at the end of surgery did not have a significant effect on the forces on the spine measured from the rod Lifting the patient from the operating table and placing him on his ward bed which was done without any particular precautions produced a mean force increase of 2 kp in the rod

Coughing during recovery from anaesthesia produced a mean increase of 2 kp in the rod Vomiting (one patient) produced an increase of 4 kp and positive pres ure breathing with a Bird respirator a mean increase of 1 kp in the rod

Cycling and arm exercises in bed three days after surgery produced no increase in rod measurements Turning the patient in bed to the convex side of the major curve produced a mean increase of 3 kp and to the concave side no increase was observed

With acute distraction (over 15 to 20 minutes) there was a linear relationship demonstrated between the externally applied force and the force simultaneously recorded on the telemetry rod in the spine This existed for both external systems - the halo pelvic apparatus and the forces applied through the skull halo and spring balance with the extension bars removed

The direct relationship between stress and strain was demonstrated illustrating elasticity as one of the mechanical properties of biological tissue

In the two patients who were assessed 60 and 80 per cent respectively of changes in the externally applied force appeared as changes in the force reasured in the spine itself by the telemetry rod

INTRODUCTION

When this clinical project commenced in 1969 studies were done both in the autopsy room and on cadaver specimens to determine the points of relative safety for inserting the pelvic pins Complications related to skull and pelvic fixation have occurred (see Part II Chapter II) the skull halo slipped and required replacing in eight patients the apparatus was removed early in five patients because of insecure pin fixation There was tearing of the peritoneum in one patient Loosening of pins with prolonged immobilisation was commonly seen

This present study was therefore expanded to define more clearly the preferred anatomical landmarks and the mechanical aspects relative to the use of the halo pelvic apparatus

The following subjects were explored

1) Fixation of the skull halo and the advantages if any of using supplementary skull pins
2) The anatomy of pelvic pin insertion with particular emphasis on defining safe landmarks
3) Basic mechanical studies of the bony ilium

1 SKULL HALO FIXATION

An autopsy study was carried out to determine the forces required to dislodge a skull halo which had been applied by the standard clinical method (Part) The ages of the four subjects ranged from 60 to 68 years and all had died of non malignant diseases Each was firmly secured to the autopsy table and the skull halo applied with the pins inserted by a torque screw driver which recorded five and one half o nd of torque force (0 06 kpm) The pins used were of the same dimensions as those used by the Rancho group (43)

A rope and pulley system was connected to the halo in such a way that the distraction force applied would be equally distributed amongst the four (or six) pins A spring balance registering up to 200 kilo pords was placed between the rope and pulley and a fixed point on the wall Traction forces were applied gradually for up to five

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1 SKULL HALO FIXATION

An autopsy study was carried out to determine the forces required to dislodge a skull halo which had been applied by the standard clinical method (Part I) The ages of the four subjects ranged from 60 to 68 years and all had died of non malignant diseases Each was firmly secured to the autopsy table and the skull halo applied with the pins inserted by a torque screw driver which recorded five and one half pound of torque force (0 06 kpm) The pins used were of the same dimensions as those used by the Rancho group (43)

A rope and pulley system was connected to the halo in such a way that the distraction force applied would be equally distributed along t the four (or six) pins A spring balance registering up to 200 kilo pords was placed between the rope and pulley and a fixed point on the wall Traction forces were applied gradually for up to five

minutes or until the halo slipped from the skull

Four pins were used routinely, when the halo slipped from the skull it was reapplied in two subjects new points of fixation, adjacent to those previously used were chosen and two supplementary pins inserted two centimetres behind the posterior pins The traction was then gradually reapplied

As for routine autopsy purposes, the upper part of the calvarium was then removed The thickness of the region of the cranium where the pins had been inserted and the depth of the pits which lodged the pins in the outer table were measured

RESULTS (Table 12)

With four skull halo pins in place a force equal to body weight or more was applied before the halo pins cut through bone and the halo slipped off In the first subject the halo could not be dislodged with a 200 kilopond force (three times the body weight) although the posterior pins had commenced to slip The anterior skull pins slipped first in the other three subjects

When two supplementary pins were added an additional 50 kiloponds of force was required to shift the halo in case 3 and in ca e 4 fixation could not be disturbed with 200 kiloponds of forre

The depth of penetration of the skull pins varied from 0 3 millimetres to 1 2 millimetres with the same amount of torque force applied it was most commonly 0 5 millimetres The deepest pin had lodged in the squamosal suture which had not fused and only the pin shouldering had prevented further penetration The average thickness of the skull at the points of pin insertion was 5 millimetres

DISCUSSION

Skull halo pins are usually inserted into the lateral aspects of the frontal bones and the posterior aspects of the temporal bones regions which are safe because of the thickness of the skull

TALLE 12

SKULL HALO F XAT OI RESULT

be	A ε & se	Body wε ght	Fo ce equı d to detach sk ll halo (apρl ed ove f ve ı ın tes)	Nu be of skull pı s used	Depth of penet atıon of skull pıns (mıllımεtres)		Comments
					Ante ıor	Posterıor	
1	ε f	ε kg	00 kk ρlus	4	0 5 0 5	0 5 0 5	Halo ın posıtıon wıth fo ces 3 tımes body weıght poste ıo pıns had co mmenced to slıp
	εε f	80 kg	80 kk	4	0 0 5	0 7 0 5	Ante ıor pıns slıpped fırst wıth fo ce equal to body weıght
	6? ı	ε kg	100 kk	4	1 0 0	0 3 0 5	Anterıor pıns slıpped fırst wıth fo ce over body weıght
			1 0 kk	ε	1 0 0	0 5 0 7 0 5 0 5	50 kk mo e fo ce need d to dıslodge halo wıth 6 pıns
4	ε5	6 kg	1 0 kk	4	0 5 0 3	0 0	Ante ıor pıns slıpped fırst wıth fo ce over twıce body weıght
			200 kp plus	6	1 0 0	1 2 1 0 0 0 5	Sıgnıfıcantly greate hold wıth two extra pıns Deep pın (1 2 mı) was ın squamosal suture

In the temporal region the frontal and temporal bones do not quite meet because of the interposition of the parietal and sphenoid bones This region of skull termed the pterion is 3 5 centimetres behind and 1 5 centimetres above the lateral margin of the bony orbit (8) It lies deep to the temporal muscle and may be paper thin on its deeper surface is the middle meningeal artery which may produce a potentially lethal extra dural haemorrhage if damaged Skull pins inserted in the temporal region may be hazardous The elected sites used clinically and in this present study are preferable for reasons of safety as the bone is so much thicker and denser

Perry (51) observed at post-mortem the pits made by the skull pins in the cranium of a patient with complete paralysis who died after having a halo on for one month They had penetrated less than two millimetres Skull bones in children are less dense and presumably the pins would penetrate the outer table to a greater depth than observed in this study

Nickel and associates in 1968 (44) reporting on the use of the skull halo in 204 patients observed only 3 case where the halo had slipped Many of the halos however had been fitted together with a body plaster and not a pelvic hoop It is likely that the forces applied through the skull halo with halo pelvic distraction are much greater than without the halo traction system This would explain the much higher incidence of skull halo slipping that we have had in our clinical experience with the halo-pelvic apparatus

Clinically the problem of the slipping skull halo has been met by 1) routine tightening of the skull pins one week after their fitting (to overcome loosening from pressure necrosis of the bone) and 2) the use of six pins when treatment is to be prolonged

2 THE ANATOMY OF PELVIC PIN INSERTION WITH PARTICULAR EMPHASIS ON DEFINING SAFE LANDMARKS

The standard clinical method of inserting the pelvic pins (47) was employed on 10 adult subjects at the time of routine autopsy Their ages varied from 40 to 70 years The instruments used included the drilling jig the carpenter s brace and two diameters of pelvic pin

(6 35 and 8 millimetres) All the pins were inserted with the aid of the jig antero posteriorly with the subject secured in the lateral position on the table The pins were inserted blindly on or rear the iliac crest and their positions subsequently inspected relative to the soft tissues in the corresponding iliac fossa and in their relationship to the bone In several instances two or three pins were drilled into the crest on the same side but from different points of entry Twenty four separate pins were inserted The bony pelvis appeared clinically normal and not misshapen in any of the subjects

RESULTS (Table 13)

The safest combination of entry and exit points was the tubercle of the crest and the posterior superior iliac spine (Fig 42 page 143) Commonly these pins stayed intraosseous throughout their entire course this depending to a large extent on the relative thickness of the bony iliac fossa at its centre In 5 out of 24 instances the pin raised the inner cortical table of the iliac fossa sometimes the middle portion of the pin was just within the fossa Here it was usually safe as the iliacus muscle forms the fossa bed when this situation arose the more flexible smaller pin was often deflected for up to 2 centimetres by the curved posterior region of the iliac fossa and the adjacent sacro iliac joint before reengaging bone and penetrating the anterior sacro iliac ligament Such pins finally emerged one or two centimetres more medial than anticipated The larger and more rigid pin steered a more direct course under these circumstances and was not deflected as far by the bony curve

Several pins were inserted inferior to the tubercle of the crest through the tensor fasciae latae and the outer table of cortical bone between the crest and the hip joint They were equally safe but at their point of entry they penetrate more soft tissue and are thus more likely to produce infection

In five cases (1R 2L 3R 5R 9L) the pin was medial to the iliacus and in one of the subjects (2) it had wrapped the peritoneum around itself These five pins were all inserted near the anterior superior spine although one of them (2L) was inserted on the crest midway between the anterior spine and the tubercle of the crest In three

TABLE 13 PELVIC PIN INSERTION RESULTS

Series number side	Age/Sex	Point of pin entry	Point of pin exit	Observations	Comments
1L	55/M	Tubercle of crest	PSIS	2 cm of length intra pelvic Raised inner table of fossa by 2 mms	Firm purchase in crest safe
R		Below crest 1 cm from AS S	PSIS	5 cm of length intra pelvic in mid course 2 cms from iliac fossa	Unsafe medial to iliacus
R		2 cm below and lateral to ASIS	PS S	2 cm of length intra pelvic in mid course	Relatively safe within iliacus
2R	60 M	2 cm from ASIS on crest	Medial to PSIS	6 cm of length intra pelvic 1 cm from iliac fossa	Relatively safe at mid point only 2 cm from femoral nerve
R		Tubercle of crest	PSIS	6 cm of length extra pelvic i e external to the crest	Safe rigid hold in bone
L		Between ASIS and tubercle of crest	PSIS	6 cm of length intra pelvic 2 cm from sigmoid colon	Had wrapped peritoneum around it Unsafe 3 cm from femoral nerve
L		Tubercle of crest (7 cm from ASIS)	PSIS	Raised inner table of iliac fossa over 3 cm	Safe secure purchase
3R	66 M	2 cm from ASIS on crest	1 cm medial to PSIS	6 cm of length intra pelvic medial to iliacus 2 cm from caecum	Unsafe
L		Tubercle of crest	1 cm medial to PSIS	Entirely within crest	Safe

TABLE 11 c t

Se ies n mbe side	Age/Se	Po t of p e try	Po t of pin e it	Obse atio s	Comme ts
4R	50/M	T bercle of crest	PSIS	8 cm of length intra pelvic (half pin diameter only)	Pin within iliacus safe
L		2 cm anterior to tubercle of crest	PSIS	7 cm of length intra pelvic raised inner table	Subperiosteal safe
5L	40/M	1 cm below tubercle of crest	PSIS	Mid portion of pin raised outer table of iliac fossa	Safe secure purchase
L		Tubercle of crest	PSIS	Entirely within crest	Safe secure purchase
R		1 cm posterior to ASIS	2 cm medial to PSIS	6 cm of length intra pelvic and medial to iliacus	In contact with caecum <u>unsafe</u>
R		Tubercle of crest	PSIS	Raised inner table of iliac fossa in mid course by 3 mm	Safe secure
6R	67/F	2 cm below tubercle of crest	PSIS	Entirely within crest	Safe secure purchase
L		Tubercle of crest	PSIS	Raised inner table subperiosteal	Safe secure purchase
7R	67/F	Mid way between ASIS and tubercle of crest	2 cm medial to PSIS	2 cm of length intra pelvic in mid course	Within iliacus safe
		Tubercle of crest	PSIS	Entirely within crest	Safe secure purchase

TABLE 13 cont

Series number + side	Age/Sex	Point of pin entry	Point of pin exit	Observations	Comments
8R	51/M	Midway between tubercle and ASIS	1 cm medial to PSIS	Intra pelvic over 4 cm of course	Deep to iliacus safe
L		Tubercle of crest	PSIS	Visible beneath periosteum of iliac fossa entirely within bone	Safe secure purchase
9R	74/F	2 cm below tubercle of crest	PSIS	Entirely within bone	Safe secure
L		1 cm posterior to ASIS	2 cm medial to PSIS	5 cm medial to iliacus	Unsafe poor purchase
10R	74/F	Tubercle of crest	PSIS	Passed outer table by 5 millimetres in mid course	Safe secure
L		2 cm below tubercle of crest	PSIS	Entirely within bone	Safe secure purchase

* ASIS Anterior superior iliac spine

PSIS Posterior superior iliac spine

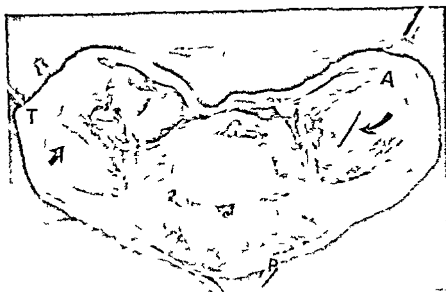


Figure 42 A section through the pelvis of an adult anatomy dissection pecimen The transve e section has been made through the l mbo acral disc with the a d of a drilling jig pelvic pir have beer in e ted throu h both iliac cre t On both des the pelvic v cera peritoreum iliacus mu cle ard the per osteum of the iliac fo sae have been stripped medially ote that (a) On the reader s r ght the pelvic pin has been ir erted through the right iliac crest beginning at he anterior superior iliac spine (A) and emerging at the posterior superior spine (P) The pin is intra pelvic in the middle of its course (arrow) (b) On the reader s left side a second pin has been inserted through the left iliac crest beginning at the tubercle of the crest (T) and emerging at the posterior superior spine Note that the pin is intraosseous throughout its course and it can be seen beneath the cortical bone of the inner table of the iliac fossa (arrow) The left anterior superior spine is marked

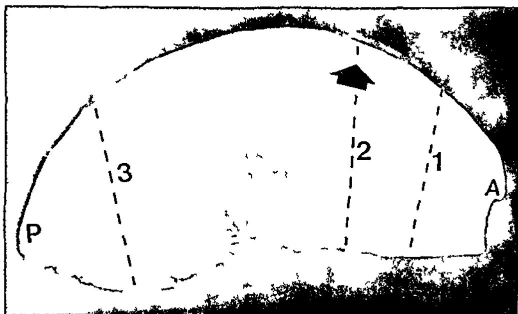


Figure 43 A lateral radiograph of an iliac crest removed at autopsy from a patient who died by accidental death Note the following points (A) the anterior and (P) the posterior superior iliac spine and the tubercle of the crest (arrow) Observe the thickness of the cortex at this point Also note the deficiency in the mid portion of the bone between two relatively thick anterior and posterior columns Bone samples 1 2 and 3 used in the study of strength of the iliac crest have been taken from areas designated 1 2 and 3 respectively in this specimen

cases (2R 5L 10R) the pin was seen external to the outer table over as much as 4 centimetres of its course Provided the purchase in the strong anterior and posterior bony columns was adequate these were considered mechanically acceptable

DISCUSSION

The ideal pre requisites for pelvic pin insertion should be
1) They should be inserted safely without exposing the iliac crest thus reducing the early incidence of infection
2) There should be no risk to the pelvic viscera
3) They should be inserted percutaneously thus minimising the amount of soft tissue exposed to the pin
4) There should be good mechanical fixation sufficient to withstand several months of treatment
5) The pins should be tolerated by the patient

The present investigation has obvious limitations the main one being that patients requiring the halo pelvic apparatus for treatment often have a poorly developed pelvis commonly osteoporotic and occasionally oblique Secondly this study has been done on a much older age group nonetheless guidelines emerge which might serve as an appropriate anatomical baseline

The crest of the ilium is cartilagenous at the time of birth With the process of ossification by the age of 9 it has been reduced to a cap of cartilage one centimetre in height (Fig 46 page 150) In this appear secondary centres of ossification at puberty (Fig 47 pa 151) which fuse with the underlying bony crest by about twenty years (F g 43) The iliac crest is then converted into a strong cortical cap particularly at the tubercle which was demonstrated by the slab radiographs (Fig 44)

The bony ilium includes the upper part of the acetabulum and the flattened area above it Three parts of it are subcutaneous the upper end whi h is the crest itself and the two projecting anterior and posterior spines The crest is convex upwards when viewed from the si e viewed from above it describes a sigmoid curve the longer medial anterior component being the iliac fossa and the smaller

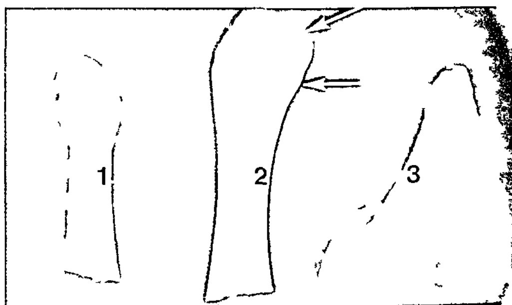


Figure 44 Slab radiographs of transverse sections of the iliac crest shown in Fig 43 and removed from the areas of the bone designated 1 2 and 3 respectively

Section 1 is a transverse section midway between the anterior superior spine and the tubercle of the crest

Section 2 is at the level of the tubercle of the crest Note the well developed cortex at both the tubercle and forming the lateral table (arrows) Note that the iliac apophysis has completely fused to the iliac crest indicating full skeletal maturity

Section 3 is taken through the posterior part of the iliac crest 3 centimetres anterior to the posterior superior iliac spine Note the medial part of the specimen includes a section through the sacro iliac joint Note particularly the absence of strong cortical bone in this specimen

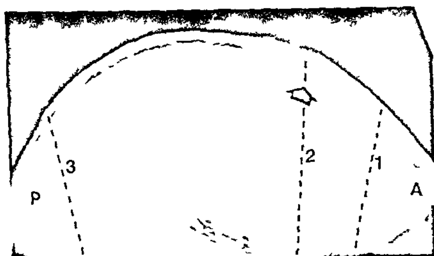


Figure 45 A lateral radiograph of an iliac crest removed at autopsy from a seventeen year old male who died by accident The anterior and posterior superior iliac spines are marked A and P respectively The tubercle of the crest is the thickest part of the crest (arrow) Note that the iliac apophysis has not yet fused with the underlying crest Note also the strong anterior and posterior columns of bone within the crests separating a large deficiency of bone in the middle of the iliac fossa

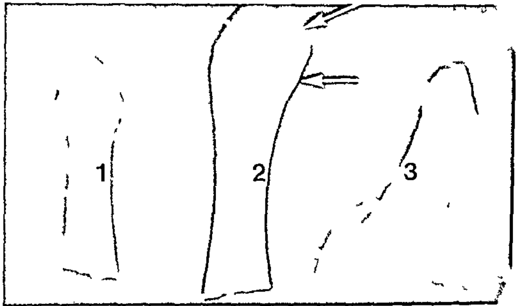
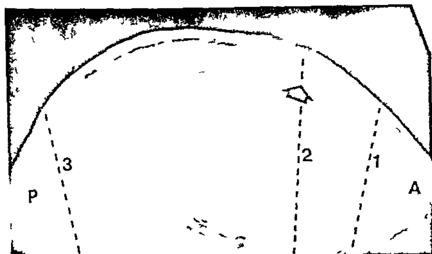


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Finure 45 A lateral radiograph of an iliac crest removed at autopsy from a seventeen year old male who died by accident The anterior and posterior superior iliac spines are marked A and P respectively The tubercle of the crest is the thickest part of the crest (arrow) Note that the iliac apophysis has not yet fused with the underlying crest Note also the strong anterior and posterior columns of bone within the crests separating a large deficiency of bone in the middle of the iliac fossa

posterior laterally directed curve being the gluteal surface Even in young children the anterior column of bone in the crest between the tubercle and the acetabulum can comprise a reasonable thickness of bone (7)

The ilium has a well developed anterior and posterior pillar of bone separated by a thin area where the cortical surfaces may be almost in contact Cunningham (8) states that the centre of the iliac fossa may even be defective The radiograph of the ilium removed at autopsy from a 17 year old patient demonstrates this deficiency in the middle of the bone (Fig 45 page 147) The iliac apophysis in this subject has completely ossified around the crest but has not yet united to it it is thickest at the tubercle of the crest

There is thus not always the possibility of having the pelvic pin in contact with bone throughout its course even when inserted as sugges ted it may be inside or outside the ilium at its midpoint because of this thinness in the middle of the ilium It is therefore preferable that the pin penetrates a reasonable thickness of cortical bone as it may be unsupported at its midpoint and therefore provides mecha nically relatively poor fixation

The iliac fossa gives origin to the iliacus muscle from the upper two thirds of its surface (8) This muscle is flat and triangular and fills the fossa It is covered by a fascial sheath medial to which is the extraperitoneal fat separating sheath from peritoneum On the right side is the caecum and on the left side the iliac part of the descending colon At the medial border of the iliacus is the psoas major and in the groove between the two lies the femoral nerve branches of which supply the iliacus muscle (L2 and L3)

There is a reasonable degree of safety permitted, when inserting the pelvic pins because of this cushion of iliacus muscle This cannot always be relied upon, it will be occasionally very thin particu larly in paralytic conditions affecting this muscle and so every effort should be made to keep the pin within the bony ilium itself

3 PASIC I.cCHA ICAL STUDIES OF THE BONY ILIUM

Initially the forces exerted by the pelvic pins on the surrounding iliac bone during distraction are mainly vertical With time there is resorption of bone around the pins for two reasons 1) immobilisation o tecporosis ard reduction of the natural compression forces reduce the n ber of cancellous trabeculae above the pins and there is a corresponding alteration of the surface area of bone in contact with th pin due to pressure n crosis 2) the constant sawing effect of the pin thread wears away the surrounding bony trabeculae When the ori ginal track housing the pin has been enlarged there will be an increase in the transverse forces and the pin will move to and fro widening the pin track even further

The aim of this study was to evaluate the holding strength of the t ercle relative to other points on the subcutaneous iliac crest An Alwetron machine (63) was used for this purpose At the same time pins of varying diameters and threads were tested to ascertain their relative purchasing potential within the bone

The mechanical strength of the iliac crest in several regions was assessed Both cres s in their entirety were removed from 7 patients who had died accidental deaths their ages ranging from 16 to 30 years

A fixed length (2 centimetres) of the standard pelvi pin was inserted into the iliac crests at three different levels a) halfway between the anterior superior spine and the tubercle of the crest (sample 1) b) at the tubercle of the crest itself (sample 2) c) several centi metres anterior to the posterior superior spine sample 3) (Fig 44 page 146) Blo ks of one encasing the pins were then excised from the crests

The length of pin was clamped in the Alwetron machine and the bone bl ck firmly secured in a brass cylinder The pin was then distracted at a star ard strain rate (one centimetre per minute) A continuous pa er tra ing provided a force defo mation ve and evider e when the pin had dislo ged

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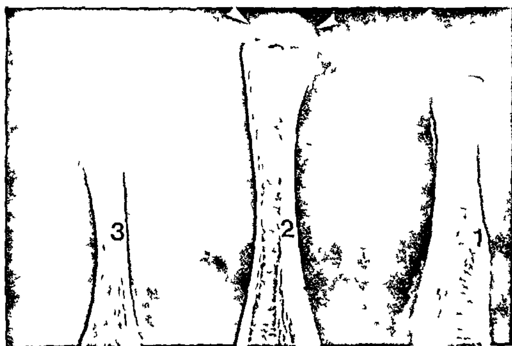


Figure 46 Slab radiographs of vertical sections of bone removed from areas 1 2 and 3 respectively (see legend Fig 44) Patient was a sixteen year old male who died by drowning Note the large cartilagenous cap of iliac crest (arrows) Note also in the radiograph of section 2 the well developed lateral cortical table

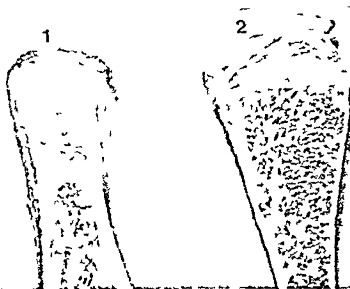


Figure 47 Fhotojraphs of vertical sections of iliac crest removed at autopsy from a seventeen year old female patient who died by accident Section 1 was cut from the anterior pa of the iliac crest and section 2 i the posterior part of the same crest Note in section 1 the carti laqenous iliac crest in which the ossific centre has appea ed This rep esents a slightly late stag of develo ment than that demonstrated in the previous adiograph (Fig 46)



Figure 48 Photographs of a male adult s left iliac crest viewed from above The crest was removed at autopsy placed in a bench vice and with a drilling jig a standard sized pelvic pin was inserted through the crest The crest was then cut open and the pin removed to demonstrate the thread created within the bone The arrow points to the anterior superior spine The pelvic pin was introduced at the tubercle of the crest (T) and it emerged at the posterior superior spine (P) Note particularly that the pin ha stayed intrao seous throughout its course

RESULTS

The bone at the tubercle of the crest (sample 2) held the pin longer than either of the other two areas examined (Table 14 page 154) The anterior sample (sample 1) was intermediate in holding ability in five of the seven specimens equal to the po terior sample in one (No 7) and weaker than it in one specimen (No 2)

The ultimate holding power of bone to any testing by this method depends on the volume of bone pre ent particularly cortical bone When the iliac apophysis has fused with the underlying crest at skeletal maturity there is a trong ridge of cortical bone on the crest particularly at the tubercle (Fig 44)

The pin were extracted with the lowest forces in bone samples from the two adolescent ubjects (cases 4 and 5) This is not surprising considering that the bony cre ts at this age have not yet fully ossified and still consist of a large proportion of cartilage (Fig 6)

Bench studies were done on four sample of iliac cre ts removed at routine autopsy They were fixed in a vice and pelvic pins inserted into them with a drilling jig The ilium was then cut down to the pin thread on one side and the bone was opened like a book (Fig 4a page 152) In each specimen tested the pin was intraosseous throughout its course The thread within the bone was firm to testing with a probe and had not been stripped by the drilling (the volume of bone replaced by the pin could be seen with a hand lens packed into adjacent cancellous trabeculae)

Pre drilling a sample of bone crest was next evaluated This is a standard engineering procedure where the hole is tapped first before he pin is inserted This method was assessed three time It produced excessive heat with the bone actually smoking from the thermal insult When the drill went outside the bone in its course the fine teeth were stripped from its end when it attempted to reengage the cortical inner table

TABLE 14

THE MECHANICAL STRENGTH OF ILIAC CREST

Case number	Sex/Age	Site of bone sample	Force required to dislodge pin from bone (kiloponds) Constant strain rate 1 cm/per minute
1	M/21	1	100
		2	210
		3	55
2	M/24	1	90
		2	220
		3	145
3	M/30	1	135
		2	210
		3	75
4	M/17	1	50
		2	90
		3	40
5	F/16	1	70
		2	110
		3	50
6	M/25	1	100
		2	190
		3	70
7	M/24	1	120
		2	190
		3	120

Legend

Site of sample			
	1	Iliac crest	half way between anterior superior spine and tubercle of crest
	2		midpoint on tubercle of crest
	3		crest 3 cm anterior to the posterior superior spine

DISCUSSION

In the skeletally mature patient the top of the crest is a thick cap of cortex In the younger patient while this cortical cap is still developing there is always a well developed outer cortical layer of the ilium which is best developed between the tubercle of the crest and the upper region of the acetabulum (Fig 46, page 150) This is firm enough for pelvic pin fixation but it has one disadvantage in that it is not subcutaneous but covered by the muscular fibres of the tensor fasciae latae

White and Hirsch (63) demonstrated that the strongest bone of the iliac crest when subjected to acute compression testing was in the region of the tubercle of the crest The ultimate ability of bone to hold a threaded pin is a reflection of the volume of cortical bone present and at the tubercle it is thicker than at other regions of the crest Currey (9) noted that the density of cortical bone is about 2 whilst that of cancellous bone varies from 0 25 to 0 8 (although the holding power of cortical bone is roughly thirty times stronger than that of cancellous bone)

It would e r that providing the crest is wide enough at the tubercle h rould be inserted here Mea urements of the width of the crest in the r ion of the tubercle in 20 samples from subjects 16 years or older va d f om 15 millimetres to 25 millimetres The pelvic pin we hav q la ly is 6 35 millimetres in diameter A larger stiffer p llimetre ha been used in the larger patients without any p blems and with the added advantage of reduced movement in t therefo e mo e likely to be tolerated by the patient ied of time without movement or infection

[illegible]

e imental conditions in adult cadavers firm the skull halo is provided by four skull pins and is when s pir are use With five and one half pound e force (0 C6 kpm) the average skull pin penetrates will tre (avera e) of the o ter table of the skull

2 Insertion of the pelvic pins is a safe procedure if a drilling jig and carpenter's brace are employed The recommended point of entry of the pin is on the tubercle of the crest or just inferior to this area the exit point the posterior superior iliac spine If a pin is inserted near the anterior superior spine it is likely to be intrapelvic and therefore dangerous

3 With ossification of the cartilagenous iliac apophysis a strong cap of cortical bone appears covering the crest at skeletal maturity This is mechanically strongest in the region of the tubercle of the crest

GENERAL DISCUSSION AND SUMMARY

The halo pelvic apparatus is not a casual alternative method of treating spinal deformities it is and should always be part of a *carefully planned approach to the management of severe* spinal curvatures It is a technique which demands discriminate selection of patients precise observation and attention to nursing care

The patients selected should have severe curves not sufficiently or efficiently corrected by any other methods in current use

The main indications for the use of the halo pelvic apparatus in this series were tuberculous kyphosis and scoliosis following poliomyelitis *If one or more of the following associated phenomena are present* 1) anaesthetic skin 2) respiratory insufficiency 3) spinal cord compression 4) a spine rendered unstable by tumour multilevel laminectomies etc 4) pelvic obliquity (provided due care is taken with insertion of the pelvic pins) then serious consideration should be given to using the halo pelvic apparatus

Great attention has been focused on pelvic obliquity and the correction achieved with the halo pelvic apparatus Only two of the eleven patients with pelvic obliquity had complete initial correction of the pelvic deformity It must be st essed again that these patients are in a high risk category because of the abnormal anatomy of the iliac crests and the subsequent possibility of perforation of intestines with pelvic pins When pelvic obliquity has been present for a long period there is such bony overgrowth on the convexity of the vertebral bodies of the scoliosis that adequate correction of the obliquity is not possible without anterior surgery

The importance of correcting the pelvic obliquity and thus providing ade uate cover for the hip joint on the higher side will be fully appreciated If one choo es the ri ht patient and plans and executes t eatment with skill and jud ement the halo pelvic apparatus is uniquely effective

This is not to pre ume that there are no problems The e have been dealt with in detail in Part II The complications must be weighed a ainst th results which could not have been achieved by other

conventional methods of correction Careful patient selection and the close observation recommended should ensure that the more serious complications do not occur Likewise, pathological changes in the cervical spine will be minimised by restricting the use of the apparatus to those patients requiring it when there is no other satisfactory means of treatment available for obtaining an acceptable result

Due consideration should be given to using the lowest corrective forces possible for the shortest period of time which is reasonable

The unique work in spinal instrumentation was commenced by Paul Harrington in 1948 It was many years later however before his method was fully accepted and now it is regarded as the treatment of choice for most forms of scoliosis It takes time and experience in many centres of the world to establish the reputation indications and precise place for a new form of treatment

The available evidence suggests that the halo-pelvic apparatus is a powerful and effective method of correcting severe spinal deformities Because of the risk of pathological changes in the cervical pine its use should be restricted to those patient with deformities which cannot be effectively treated by the other methods in use today

SUMMARY

Part I

1) The history of the development of the halo pelvic apparatus is discussed together with a general description of the apparatus The fitting of the apparatus is described in detail with emphasis laid on the accurate insertion of the pelvic pins the use of the drilling jig and precise points of entry and exit in the iliac crest being the tubercle on the crest and the posterior superior iliac spine respectively

2) During the post-operative period the four extension bars are placed connecting the patient s skull halo to the pelvic hoop For reasons of safety this is not done at the time of the fitting of the

3) Any patient with a spinal deformity severe enough to require treatment with the halo pelvic apparatus should have pre-operative myelography and respiratory function studies done

4) The four base lines which must be used to monitor the patient during distraction are a) regular clinical observation b) daily neurological assessment c) regular lateral radiography of the cervical spine and d) the use of force measurement

5) When the halo pelvic apparatus is removed a plaster body cast is applied until the bone graft has consolidated

Part II

6) One hundred and four patients with severe spinal deformitie commenced treatment with the halo pelvic apparatus The most common etiologies of the deformity treated were tuberculous kyphosis and paralytic scoliosis There were four deaths following surgery in the series he average time the patients spent in the apparatus was 7 5 months 21 pe cent of the patients had cord compression or frank pa aplegia at the onset of treatment

he average correction of the deformity was as follows tu er ulo kyphosis 31 per cent paralytic scoliosis 51 per cent idio path scol osis 42 per cent congenital kyphoscoliosis 26 per cent nr f e fib oma osis kyphoscoliosis 43 per cent These patients who ... on es for p eviously failed posterior fusion had an ... o tion of 40 per cent

... most common significant complication due to the use of the halo ... a pa atus was associated with distraction of cervical spine (77 ... with adiographs of cervical spine were examined) Degenera... es in the posterior joints of the cervical spine (34 per ... and a a ular necrosis of the u er pole of the dens (17 per ... we e the mos common neck complications Some of the patients with chan es in the a is also had osterior joint changes therefore these centa s shoul be inter reted accordingly Cranial nerve ... ra a was occu red in 7 per cen of the patients and brachial

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Mechanical studies of the iliac crest confirmed that the bone in the region of the tubercle of the crest is stronger than in other regions of the bone providing yet another reason why that area should be used for inserting the pelvic pins

plexus palsies in 3 per cent of the patients Temporary spasticity in the lower limbs occurred in the 3 per cent of patients A torn peri toneum occurred during insertion of the pelvic pins in one patient Laparotomy confirmed that no other damage had been done Although many patients had discharge associated with the pelvic pins, it was unusual for them to present clinical problems

Part III

9) In four patients with severe paralytic scoliosis a study wa done to determine the amount of force which was transmitted through the spine by the halo-pelvic apparatus This was done by comparing force measurements on the halo-pelvic compression springs with the internal readings from the specially designed telemetry rod

Replacing the extension bars onto the halo and pelvic hoop at the end of posterior pinal urgery did not have a significant effect on the forces on the spine measured from the rod Lifting the patient from the operating table produced a mean force increase of 2 kp in the rod With acute distraction over 15 to 20 minutes a linear rela tionship was demonstrated between the externally applied forre and the force simultaneously recorded on the telemetry rod in the pine The direct relationship between stress and strain was demonstrated confirming elasticity as one of the properties of biological tissue In the two patients who were assessed 60 per cent and 80 per cent respectively of changes in the externally applied force appeared as changes in the force measured in the spine by the telemetry rod

Part IV

10) With autopsy experimentation using five and a half pound inches of force on the torque screw driver (0 06 kpm) the average skull pin penetrates 0 5 mm (average) of the outer table of the skull

Insertion of the pelvic pins is safe if a drilling jig and a carpen ter's brace are used The ideal point of entry for the pin is at the tubercle of the crest or just inferior to this area, and the ideal exit point is the posterior superior iliac spine If a pin is inserted near the anterior superior spine it is likely to be intra-pelvic and therefore dangerous

APPENDIX A

SUMMARY OF CLINICAL MATERIAL

	T BER O S KYPHOSIS	KYPh SCOLIOSIS			
Eti l y	T berculo s	Paralytic	Idiopathic	Concenital	Neurofibromatosis
N e of a le ts	42	31	15	10	6
A of o set of deformity (a e a e	1 5 yrs	2 y s	14 yrs	birth	12 yrs
A e t eat ent co e ced a e a e	16 1 y s (3 26 y s)	14 1 y s (6 25 y s)	15 6 yrs (6 21 y s	12 8 y s (6 19 y s	13 8 y s (10 19 y s)
Le th of t me n a na at s i mo ths (ave a e)	8 4	7 6	6 4	5 5	8
Peak le el of deform y	T9	T10 11	T10 11	Thoraco lumbar	T9 10
e ees of defo mity	117^{o}	111^{o}	82^{o}	66^{o}	98^{o}
o ect o at follow u	87^{o}	59^{o}	48^{o}	61^{o}	1^{o}
Cc e o de es o d of t a t o	75	1 32	52	65	1 4
N of c e at o s pe pat e t	3	2	1	2	2
Rad o cal ra e c al s e at	14 4	1 7	4 45	6 1	50
Lee t o	0	3 3	2 4	1	1

APPENDIX B

CLINICAL DATA OF 104 PATIENTS

TUBERCULOU" KYPHOSIS

No	Se A	Le el e te t of deform ty	P e o s su e y	P e op co d comp ess o	Spi al operations	T me in appa at s (months)	Co ectio From	To		Fi al	Follow p (years)
1	F/15	8 L1	F s on		3 ASO) PSO) ASF PSF (late)	12	106°	70°	34	1?5°	4 5
2	M/15	T4 T9			3 ASO ASF PSF	6	135°	90°	33%	92°	4
3	M/6	T5 T9	Deb ide me t		2 ASO ASF	4	70°	46°	34%	50°	4
4	F/6	T5 T9			3 ASO ASF PSF (late)	5	81°	40°	51%	62°	4
5	F/16	T8 T12	Fusion		3 ASO) PSO) ASF PSF	5	125°	90°	28%	105°	4
6	M/13	T9 L1			2 ASO ASF	6	120°	105°	13	115°	4
7	M/21	T8 T12	Fusion	+	3 ASO) PSO) ASF PSF	3	134°	103°	23	113°	3 75
8	M/20	T6 L2			3 ASO) PSO) ASF PSF	11	133°	90°	32	90°	3 75



17	F 20	T6 L		4	A S O P S O A S F P S F	12	146°	93°	36	93°	3
18	F/21	T6 L2		3	A S O A S F P S F	12	107°	15°	86	42°	3
19	M/19	C7 T5	F S10	4	A S O P S O A S F P S F	10	118°	62°	47	62°	3
20	M/15	T6 L1		4	A S O P S O P S F A S F	10	1,1°	63°	48	63°	2 75
21	M/18	T11 L2		4	A S O P S O A S F P S F	11	112°	97°	13%	97°	2 75
22	M/6	T9 L4		2	P S F A S F	8	85°	55°	35	65°	2 75
23	F/20	T7 T12		3	A S O P S O) P S F) A S F	8	134°	76°	43	77°	2 5
24	F/23	T7 T10	Fusion	3	A S O P S O) P S F) A S F	10	89°	70°	21%	72°	2 5
25	M/3	T11 L2		2	A S F P S F	7	70°	44°	37	54°	2 25

TUBERCULOUS KYPHOSIS

No	Sex/Age	Level extent of deformity	Previous surgery	Pre op cord compression	Spinal operations		Time in apparatus (months)	Correction				Follow up (years)
								From	To		Final	
9	M/16	T8 T11			3	A S O) P S O) A S F P S F	10	125°	92°	24	93°	3 75
10	F/19	T8 L4		+	4	A S O P S O A S F P S F	16	142°	81°	43	105°	3 75
11	M/15	T9 L1			3	A S O) P S O) A S F P S F	12	103°	75°	26	81°	3 5
12	M/22	T2 T9	Fusion		4	A S O P S O A S F P S F	12	126°	82°	35	82°	3 5
13	M/19	T8 L1	Fusion		4	A S O P S O A S F P S F	15	137°	98°	28	100°	3
14	F/5	T2 T4			2	A S F P S F	6	59°	40°	32*	45°	3 25
15	M/18	T6 T10			4	A S O P S O A S F P S F	11	138°	102°	26%	120°	3 25
16	M/15	T10 L1	Fusion		5	A S O P S O x2 A S F P S F	12	91°	68°	25%	81°	3 25

35	M/18	T6 T12	Debride ment	4	A S O P S O A S F P S F	7	144^0	44^0	70	44^0	1 75
36	M/18	T10 L1		4	A S O P S O P S F A S F	7	137^0	110^0	20%	130^0	1 75
37	M/22	T8 L1		2	A+P S O A P S F	9	134^0	125^0	7%	130^0	1 5
38	F/18	T6 T11		3	A S O P S O +F A S F	3	128^0	110^0	14%	110^0	1 5
33	F/14	T6 L2		4	A S O x2 A S F P S F	12	125^0	108^0	14	108^0	1 25

<u>Deaths</u>

					<u>Cause of death</u>
40	F/19	T6 T12	132^0	Fusion	Paralytic ileus and pneumonia
41	F/20	T5 T14	145^0		Respiratory failure
42	F/18	C2 T5	109^0		Respiratory failure

The apparat s was used as a means of external spine fixation not distraction

TUBERCULOUS KYPHOSIS

No	Sex/Age	Level extent of deformity	Previous surgery	Pre op cord compression	Spinal operations	Time in apparatus (months)	Correction From	To		Final	Follow up (years)
26	F/26	T8 L3			4 A S O P S O P S F A S F	9	123°	73°	41%	73°	2 25
27	M/23	T9 L2	Fusion	+	4 A S O P S O P S F A S F	10	133°	94°	29	94°	2 25
28	F/6	Holding			3 A S O A S F P S F	4	Holding				3
29	M/16	T7 T10		+		1	Early removal				3
30	M/11	L3 L5			2 A S F P S F	1	Early removal				2 25
31	M/18	T6 T10		+	3 A S O P S O) P S F) A S F	9	147°	109°	26%	109°	2 25
32	F/11	T2 T8		+	2 A S F P S F	5	99°	91°	8	91°	2
33	M/17	T5 T8		+	4 A S O P S O A S F P S F	8	105°	93°	12%	93°	2
34	M/19	T5 L2		+	4 A S O P S O A S F P S F	9	136°	125°	8	125°	2

[illegible]	M/13	2	T10 L5		P S F Dwyer	11	116°	37°	68	37°	46°	3 5
57	M 20	6	T6 L1		P S F rod Rib e cision A S F	10	144°	68°	53		68°	3 2
58	F/11	2	T5 T11		P S F x2 Rod	10	74°	29°	61%		37°	3 25
9	F/16	6/12	T7 L3		P S F Rib excision	11	92°	55°	48%		59°	3 25
60	M/17	3	T11 L5		P S F x2 Dwyer	9	72°	28°	60		30°	3 25
61	F/18	13	T4 L5	Fusion	A S F P S F +rod	7	28°	20°	29		20°	3
62	F/14	1	T10 L4		Dwyer P S F x2	9	117°	68°	42	32°	37°	3
63	M/16	4/12	T10 L5		A S F Dwyer P S F x2	14	151°	76°	49	65°	70°	3
64	M/16	10/12	T12 L4		Dwyer P S F +rod P S F	9	83°	41°	51%	24°	24°	3
65	M/13	3	T5 T12		P S F x2	10	100°	48°	52		65°	2 75
66	F/13	4	T12 L5		P S F x2 Dwyer	2	Early removal					2 5
67	F/14	2	T11 L5		Dwyer P S F x2	9	108°	61°	40%	29°	28°	2 5
68	M/6	2/12	T4 L5		No op	2	Early removal					2 5

PARALYTIC SCOLIOSIS

No	Sex/Age	Age onset	Level extent of deformity	Previous surgery	Pre op cord compression	Spinal operations	Time in H P T (months)	Correction From	To	%	With Dwyer	Final	Follow up (years)
43	M/11	10/12	T5 T12	Fusion		S O P S F	7	97°	74°	24%		97°	4 75
44	F/11	5	T4-T10			P S F +rod	4	82°	38°	53%		49°	4 75
45	M/14	2	T6 T12			P S F	4	110°	77°	30	-	86°	4 75
46	M/17	1	T10 L5			P S O Dwyer	2	120°	53°	57%	73°	90°	4 5
47	F/12	4	T4 T10			P S F	1	59°	25°	59	-	56°	4 5
48	M/12	1	T11 L5			Dwyer P S F	1	Early removal					4 5
49	F/12	1	T3 L2		-	P S F x2 Rib excision	11	142°	55°	65%		78°	4 25
50	F/25	3	T5 T12		-	P S O Dwyer Rib excision	5	105°	80°	24%	42°	58°	4
51	F/14	5	T3 T11			P S F x2 Rib excision A S F	11	135°	56°	57%		68°	3 75
52	M/9	9/12	T5 L5		-	P S F	13	112°	21°	81%		60°	3 75
53	F/18		T3 T11			P S F	9	118°	88°	25%		103°	3 75
54	M/8	3/12	T10 L5		-	P S F	12	100°	44°	56%		40°	3 5
55	F/21	3	T4 T10			P S F Rib excision	9	136°	85°	47%		98°	3 5

D OPATHIC SCOLIOSIS

No	se Age	Lev of maj deform ty	Pe o s su ge y	T me H P T (months)	Spinal ope ations	Co e t o From	To	with Dwye	Final	a	Follow-up (yea s)
74	F/14	T4 T11 T11 L4		10	P S F 2	97°	35°		35°	64	3
75	F 18	T7 L4	Osteotomy	12	P S F	75°	33°		33°	56	3
76	F/12	T10 L4		12	P S F	74°	33°		43°	55	3
77	F 15	T6 T11		10	P S F	90°	39°		49°	57	3
78	F/16	T11 L4		2	Dwyer	70°	30°	0°	0°	57:	3
79	F 21	T6 L1		11 5	P S F rod	98°	71°		71°	28	2 75
80	M 1	T3 T10		2	Dwyer	90°	59°	40°	49°	34	3
81	F/16	T5 T10		6	P S F rod	77°	60°		77°	22	2
82	F 19	T9 L2	Osteotomy	9	P S F A S F	94°	57°		57°	39	2
83	F/18	T5 T12		4	P S F rod	80°	63°		65°	21	2
84	F/16	T6 T12		6	P S F rod	80°	55°		57°	31	2
85	F/14	T11 L4		1	Dwyer	47°	35°	0°	0°	25	2
86	F/15	T4 T11	Fusion	3	Osteotomy of P S F rod	62°	52°		52°	16	2
87	F/13	T8 T12	Fusion	4	Osteotomy of P S F rod	92°	4?°		48°	48	1 5
88	F 13	T5 T11		4	P S F rod	9 °	[illegible]		58°	44	1 5

k ference fo t eatment from o si h ng to a

PARALYTIC SCOLIOSIS

No	Sex/Age	Age onset	Level extent of deformity	Previous surgery	Pre op cord compression	Spinal operations	Time in H P T (months)	Correction					Follow up (years)
								From	To		With Dwyer	Final	
69	F/16	10/12	T5 L5		-	P S F x4	15	164^0	78^0	52		98^0	2
70	F/13	1	T5 L3	Fusion		P S O x2 P S F x2	8	110^0	50^0	55%	-	70^0	2
71	M/11	1	T7-L5			Dwyer P S F x2 Rods	4	126^0	63^0	50	35^0	45^0	2
72	M/13		T6 L2			Dwyer P S F +rod	5	120^0	65^0	46%	34^0	40^0	1 75
73	F/14		T10 L5	Fusion		P S O +F A S F	3	Holding					1 5

NE OFIBROMATOSIS KYPHO COLIOSIS

No	Sex Age	A e	m t	t P o s g y	P op ne olog cal stat s	Sp al op at ons	T in H P T (mo ths)	Cor ection F om	To		Fi al	Follow up (yea s)
97	F 1	9	1 12	Fus o	Paraplegia	A S F	5	72°	59°	18	79°	4 5
1 J	F 13	6 12	T T10			P S F	5	100°	53°	47	71°	4
31	F 1		L3			A S F P S F	10	85°	35°	59	45°	3 5
102	F 1		T9 L1			P F P S F A S F	7	131°	20°	85	70°	3 5
103	M 10		oldi g	Lam nec to es	Pa apleg a	A S F P S F	6	Holding[x]				2
104	M 19		TP T10	a nec to es	Pa aplegia	A S O A S F P S F	15	105°	99°	6	99°	5

The app atus was d as a n a s of e t nal spi al fi ation ot distraction

Refe e ce fo t ea m t f m o side H ng te g

CONGENITAL KYPHOSCOLIOSIS

No	Sex/Age	Level extent of deformity	Previous surgery	Pre op cord compression	Spinal operations	Time in H P T (months)	Correction From	To		with Dwyer	Final	Follow-up (years)
89	M/8	Thoraco lumbar		+	Excision hemivertebrae	4	Holding[x]					4
90	F/6	Thoraco lumbar			A S O +F P S F	4	Holding[x]					3
91	F/12	T11 L4			P S O Dwyer P S F	7	67°	32°	48	11°	13°	3
92	M/13	T9 L1		-	P S O +F A S F	9	125°	60°	48		65°	2
93	M/19	T9 L4			A S O P S O +F A S F	8	104°	77°	26		82°	2
94	F/12	T1 T7			P S F P S F +rod	5	84°	65°	23		70°	2
95	F/17	T4 T10			P S O P S F	3	85°	72°	15	-	-	2
96	F/15	T8 T10			Died							
97	F/14	T11 L4			P S O P S F +rod	3	75°	64°	15		75°	2
98	M/12	T11 L4		+	A S O A S F P S F	7	63°	59°	6	-		1

[x] The apparatus was used as a means of external spinal fixation not distraction

* Reference for treatment from outside Hong Kong

LIST OF REFEREN CES

1 A ADAMKIEWICZ A Die Blutgefasse des Menschlichen Ruckenmarkes S B Heidelb Akad Wissensch , 1882

2 B EIG A Biomechanics of the central nervous system Almqvist & Wiksell Stockholm 1966

3 CASS, C A & DWYER A F A drilling jig for arthrodesis of the hip J Bone Jt Surg 51 B 135 1969

4 CHALMERS J Distribution of osteoporotic changes in the ageing skeleton Clinics in Endocrinology & Metabolism 2 203 1973

5 CLARK J A & KESTERTON L Halo pelvic traction appliance for spinal deformities J Biomechanics 4 589 1971

6 CLARK J A HSU L C S & YAU A C M C Visco elastic behaviour of deformed spines under correction with halo pelvic distraction J Bone Jt Surg 56 A 441 1974

7 C OCKFORD D W & CO VERSE J M The ilium as a source of bone grafts in children Plastic and Reconstructive Surgery 50 270 1972

8 CU NI HAM s Textbook of Anatomy Oxford Medical Publications 9th edition London 1951

9 CU EY J D he mechanical pro erties of bone Clin Orthop 73 210 19 0

10 DewALD R & RAY R D Skeletal traction for the treatment of se e e scoliosis J Bone Jt Surg 52 A 233 1970

11 wan D R MULCAHY T M SCH LTZ A B Force measurement stud es with the halo ho p a paratus Le ture at the Annual Meeting of the Scoli sis esearch Society Wilmington Delaware Septe ber 1972

23 GARRETT A L PERRY J & NICKEL V L Paralytic scoliosis Clin Orthop 21 117 1961

24 GREEN W Personal communication 1972

25 HARRINGTON P Surgical instrumentation for management of scoliosis J Bone Jt Surg 42 A 1448 1960

26 HARRINGTON P R & DICKSON J H An eleven year clinical investigation of Harrington instrumentation a preliminary report on 578 cases Clin Orthop 93 82 1973

27 HODGSON A R Correction of fixed spinal curves A preliminary communication J Bone Jt Surg 47 A 1221 1965

28 HODGSON A R SKINSNES O K & LEO G C Y The pathogenesis of Pott s paraplegia J Bone Jt Surg 49 A 1147 1967

29 HOLLINSHEAD H Anatomy for surgeons vol 3 The back and limbs Hoeber Harper International Edition Ch 2 174 1966

30 IRWIN C E The ilio tibial band Its role in producing deformity in poliomyelitis J Bone Jt Surg 31 A 141 1949

31 LEWIN D Personal communication 1970

32 LUNDBORG G & RYDEVIK B Effects of stretching the tibial nerve of the rabbit A preliminary study of the intraneural circulation and the barrier function of the perineurium J Bone [illegible] 5 B 390 1973

[illegible] Heat and bone tissue Scand J Plastic and [illegible]constructive Surg [illegible] 9 1972

34 [illegible] C The use of halo pelvic distraction in preoperative [illegible] of [illegible]coliosis J Bone Jt Surg [illegible] 1974

35 [illegible] L F[illegible] studies of fixed paralytic pelvic obliquity J [illegible] 18 87 1936

12 DeWALD R L New trends in the operative treatment of scoliosis Current Practice in Orthop Surg 1973, p 206

13 DOMMISSE G F The blood supply of the spinal cord A critical vascular zone in spinal surgery J Bone Jt Surg 56 B 225 1974

14 DWYER A F , NEWTON, N C & SHERWOOD A A An anterior approach to scoliosis A preliminary report Clin Orthop 62 192 1969

15 DWYER A F Experience of anterior correction of scoliosis Clin Orthop 93 191 1973

16 DWYER A F & SCHAFER M F Anterior approach to scoliosis J Bone Jt Surg 56-B 218, 1974

17 ELFSTRÖM, G Intravital wireless telemetry of forces during and after surgical correction of scoliosis *Chalmers University of* Technology Technical report No 26, 1972

18 ELFSTRÖM, G & NACHEMSON A Telemetry recordings of forces in the Harrington distraction rod A method for increasing safety in the operative treatment of scoliosis patients Clin Orthop 93 158 1973

19 ELFSTRÖM G NACHEMSON A & O BRIEN J The mechanical effect *of the halo pelvic apparatus as measured by telemetry* J Bone Jt Surg 56 A 444 1974

20 ENNEKING W F & HOROWITZ M The intra articular effects of immobilization on the human knee J Bone Jt Surg 54-A 973 1972

21 EVARTS, C M WINTER R B & HALL J E Vascular compression of the duodenum associated with the treatment of scoliosis Review of literature and report of 18 cases J Bone Jt Surg 53 A 431 1971

22 FRANKEL V H & BURSTEIN, A H Viscoelasticity In Orthopaedic Biomechanics Lea & Febiger Philadelphia p 96 1970

47 O BRIEN J P & YAU A C M C An erior and pos erior correction and fusion for paralytic scoliosis Clin Orthop 86 153 1972

48 O BRIEN J P Ya n A C M C & Hodgso n A R Halo pelvic traction a techn q e for evere spiral deformities Clin Orthop 93 127 1973

9 C u G B Personal communication 1974

50 PERRY J & NICKEL V L Total cervical spine fusion for neck paralysis J Bone J Surg 41 A 37 1 59

51 PERRY J Personal communication 1971

52 PERRY J The halo in spinal abnormalities Practical factors and avoidance of complications Clin orth Am 3 1 69 1972

53 REL C J E S & Wal J E An operation frame for spinal fusion A new apparatus de igned to reduce haemorrhage during operation J Bone Jt urg 49 B 327 1967

54 ROAF R Vertebral growth and its mechanical control J Bone Jt u g 42 B 0 1960

[illegible] R B Personal communication 1972

56 [illegible] H J Peripheral nerve injuries M R C Special Report eries o 82 Her Majesty s Stationery Office 19 4

5 [illegible] H J Surgical Disorders of the Peripheral Nerves Ch urchill Livingstone Edinburgh & London 73 1972

58 [illegible] S Personal communication 1971 & 1972

9 [illegible] S [illegible] er es and nerve injuries E & S Livingstone [illegible] 63 1 1968

60 T [illegible] J & [illegible] J P [illegible] cular necrosis of the [illegible] al end of the [illegible] complication of halo pelvic distraction J [illegible] 57 A 332 1975

36 MOE, J H A critical analysis of methods of fusion for scoliosis, an evaluation of two hundred and sixty-six patients J Bone Jt Surg 40-A 529 1958

37 MOE J H Complications of scoliosis treatment Clin Orthop 53 21, 1967

38 MOE, J H The management of paralytic scoliosis Southern Medical Journal 50 67 1957

39 MORTON J & MALINS P The correction of spinal deformities by halo-pelvic traction Physiotherapy, December 576, 1971

40 NACHEMSON, A & ELFSTRÖM G A force-indicating distractor for the Harrington rod procedure J Bone Jt Surg 51-A 1660, 1969

41 NACHEMSON, A & ELFSTRÖM, G Intravital wireless telemetry of axial forces in Harrington distraction rods in patients with idiopathic scoliosis J Bone Jt Surg 53 A 445, 1971

42 NELSON J Direct pelvic traction with rigid skeletal fixation Resident papers Rancho Los Amigos Hospital 41-46 1969

43 NICKEL V L , PERRY J , GARRETT A & NELSON R Application of the halo Orthop Prosth Appl J , March 31 1960

44 NICKEL V L PERRY J GARRETT A & HEPPENSTALL M The halo A spinal skeletal fixation device J Bone Jt Surg 50 A 1400 1968

45 O BRIEN J P YAU A C M C & HODGSON A R Halo pelvic traction a new method of external spinal instrumentation for the correction of kyphotic and scoliotic deformities Far East Med J 6 146 1970

46 O'BRIEN, J P YAU, A C M C SMITH T K & HODGSON A R Halo pelvic traction J Bone Jt Surg 53 B 217 1971

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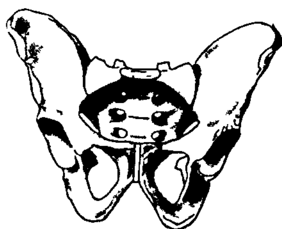
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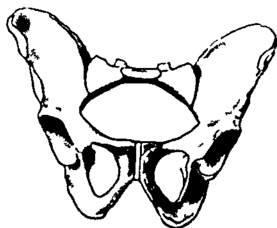
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This thesis is based on the following papers, which, in the text, will be referred to by their Roman numerals

I – Gunterberg B. Norlén L. Stener B. & Sundin, T
Neurourologic evaluation after resection of the sacrum.
Accepted for publication in Investigative Urology

II – Gunterberg, B. & Petersén I
Sexual function after major resections of the sacrum with bilateral or unilateral sacrifice of sacral nerves.
Submitted for publication in Fertility and Sterility

III – Gunterberg, B. Kewenter J Petersén, I. & Stener B.
Anorectal function after major resections of the sacrum with bilateral or unilateral sacrifice of sacral nerves.
Submitted for publication in British Journal of Surgery

IV – Gunterberg, B. Romanus, B. & Stener B.
Pelvic strength after major amputation of the sacrum.
An experimental study
Submitted for publication in Clinical Orthopaedics and Related Research.

CONTENTS

INTRODUCTION

The main indication for a major resection of the sacrum is a life threatening tumour. The symptoms of tumours in this region are often vague such as low-grade, sometimes periodic, pain in the sacral region and only in advanced cases may there be more obvious disturbances like pressure on the rectum or impairment of lumbosacral nerve function, not seldom interpreted as being caused by disc protrusion. Thus, tumours in this area are often detected only when they have reached a considerable size, causing hesitation and irresolution when surgical treatment is considered.

The reasons for this are threefold: (1) expected technical difficulties during the operation, (2) doubts as to the postoperative function of the bladder, genitalia and anorectum, and (3) uncertainty concerning the strength of the remaining sacroiliac regions.

Surgical procedures and factors limiting surgery in cases of tumours of the retrorectal or sacral regions are not well established. Not even in a modern handbook of surgery of the spine is sacral resection mentioned although both lumbar and coccygeal surgery are described (Rathke and Schlegel 1974). An abdominosacral approach is proposed by Freier et al. (1971) in the management of most retrorectal lesions greater than 5 cm in size, regardless of histological type. Steckler and Martin (1974) point out that the second sacral segment is the factor limiting the extent of resection since removal of this segment would lead to permanent and severe neurological damage. Resections more extensive than the three lower sacral segments are said to result in instability and collapse of the pelvis and descent of the lumbar spine (Pearlman and Friedman 1970). Nevertheless, Bowers (1948), MacCarty et al. (1952), Hays (1953), and Localio et al. (1967) have demonstrated the possibility of removal of the lower four segments of the sacrum and, in the case of Hays, even half the first sacral vertebra, without serious disabling consequences to pelvic stability. However, dislocation of the pubic symphysis was found in one of the cases reported by MacCarty et al., but this patient had a recurrence of fibrosarcoma only 2 months after discharge from hospital which might have influenced pelvic stability. Wilson (1972) has described a unilateral resection of the upper part of the sacrum, including the articular surfaces of the sacroiliac joint with bridging of the gap with a bone graft consisting of the posterior third of the ipsilateral ilium. No insufficiency of the supporting function of the graft developed in this young patient.

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The reasons for this are threefold (1) expected technical difficulties during the oper ation (2) doubts as to the postoperative function of the bladder genitalia and ano-rectum, and (3) uncertainty concerning the strength of the remaining sacroiliac regions.

Surgical procedures and factors limiting surgery in cases of tumours of the retrorectal or sacral regions are not well established. Not even in a modern handbook of surgery of the spine is sacral resection mentioned although both lumbar and coccygeal surgery are described (Rathke and Schlegel 1974). An abdominosacral approach is proposed by Freier et al (1971) in the management of most retrorectal lesions greater than 5 cm in size regardless of histological type Steckler and Martin (1974) point out that the second sacral segment is the factor limiting the extent of resection since removal of this segment would lead to permanent and severe neurological damage Resections more extensive than the three lower sacral segments are said to result in instability and collapse of the pelvis and descent of the lumbar spine (Pearlman and Friedman 1970). Nevertheless, Bowers (1948) MacCarty et al. (1952), Hays (1953), and Localio et al (1967) have demonstrated the possibility of removal of the lower four segments of the sacrum and in the case of Hays, even half the first sacral vertebra, without serious disabling consequences to pelvic stability However dislocation of the pubic symphysis was found in one of the cases reported by MacCarty et al. but this patient had a recurrence of fibrosarcoma only 2 months after discharge from hospital which might have influenced pelvic stability Wilson (1972) has described a unilateral resection of the upper part of the sacrum, including the articular surfaces of the sacroiliac joint, with bridging of the gap with a bone graft consisting of the posterior third of the ipsilateral ilium. No insufficiency of the supporting function of the graft developed in this young patient.

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Further the question rose of to what degree the pelvic ring is weakened by a major amputation of the sacrum and what residual strength is retained in the posterior arch of the pelvis Is there any risk of pelvic failure upon full weight bearing at an early stage postoperatively? A biomechanical study was therefore undertaken concerning pelvic strength after major sacral amputation

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In cases of tumours necessitating sacral resection to varying extent it is as a rule possible by preoperative examinations of various kinds, and careful planning to calculate the necessary sacrifice of nerves and skeletal parts. Therefore through our studies, we hoped to be able to collect data permitting, for example prediction of the degree of urogenital and anorectal disability and the risks of standing and walking with full weight-bearing that these patients would encounter postoperatively

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trusor part of the bladder mucosa is said to be supplied mainly by thoracolumbar and the trigone predominantly by sacral afferents. The existence of thermaesthesia of the bladder mucosa is the subject of controversy

The sex act

The events of the sex act are comparable in both sexes if the embryological development of the respective structures is taken into account. *Erection* of the penis in the male analogous to the tumescence of the clitoris and labiae minorae in the female is brought about by psychogenic and/or reflexogenic stimuli which accomplish arterial dilatation in the corpora. The impulses are mediated by the parasymphathetic pelvic nerves (S 2 S 4) In addition sympathetic impulses from thoracolumbar segments may be responsible as has been shown in animals and confirmed by clinical findings. *Emission* of semen in the male by contraction of the vasa and seminal vesicles corresponds in the female to the contraction of the smooth musculature of the tubes and uterus and th expulsion of the contents of the glands of Skene It is dependent on impulses travelling in the fibres of the sympathetic thoracolumbar outflow *Ejaculation* in the male corresponds in the female to rythmic contractions of the musculus sphincter cunni (the equivalent of the ischiocavernosus and bulbocavernosus muscles in the male) Emission triggers off afferent impulses from the prostatic and membranous urethra travelling in the pudendal and possibly pelvic nerves to the sacral cord (S 2 S 4) where they elicit efferent impulses mediated by the pudendal nerves which effect clonic contractions of the pelvic floor muscles. The smooth muscles of the vesical neck contra t in response to efferent impulses from thoracolumbar segments to prevent regurgitation of the ejaculate into the bladder *Detumescence* of the corpora in the male and the clitoris and labiae in the female is accomplished by sympathetic impulses causing vasoconstriction. *Orgasm* precedes and accompanies emission and ejaculation. It may be retained in one form or another as long as either the autonomic innervation of the adnexa or the somatic innervation of the pelvic floor musculature remains intact.

Faecal continence and defaecation

Continence depends partly on the configuration of the anorectal region and partly on the action of muscles. The main factors are the angulation between the rectum and the anal canal maintained by the pull of the puborectalis muscle (innervated by the pudendal nerves S 2 S 4) the anteroposterior slit of the anal canal which accounts for a flutter valves mechanism, and the tonic activity of the internal anal sphincter (excitatory impulses via the hypogastric nerves and inhibitory impulses through the parasympathetic pelvic nerves). Additional support is provided by the external anal sphincter (innervated by the pudendal nerves) whose main function is to give emergency protection voluntarily for up to one minute The entry of faeces from the sigmoid colon

CLINICAL STUDIES
ON UROGENITAL AND ANORECTAL FUNCTION

Bnef reviews of relevant present concepts on urogenital and anorectal function with special reference to segmental innervation

Several textbooks and reviews on these concepts have been published and the reader is referred to these for further details (e g Bors and Comarr 1960, Schuster 1968, Kerre mans 1969 Hotchkiss 1970 Bors and Comarr 1971 Duthie 1971, Carlsson and Sun din 1974)

Urinary continence and voiding

The anatomical arrangement of the structures round the bladder neck provides a »pass 1 e» continence mechanism The striated pelvic floor muscles including the external urethral sphincter innervated by the pudendal nerves (S 2 S 4) are necessary for this continence only during brisk increases of the intraabdominal pressure as for instance during coughing »Active» continence, which means voluntary inhibition of micturition is achieved by contraction of the external urethral sphincter The mechanism of adapt ation of the bladder wall during bladder filling i e how an increase in the bladder press ure is counteracted has not been fully explored At moderate and large bladder vol umes adaptation is thought to be achieved via afferent impulses in the pelvic nerves and efferent inhibitory impulses in the sympathetic hypogastric nerves (T 11 L 2) bringing about a bladder relaxation During filling of the bladder a first sensation of fulness is experienced at about half the bladder capacity and a desire to void when the bladder is nearly full These sensory impulses are mediated via the pelvic nerves Mict urition may be voluntarily suppressed or facilitated In the latter case a co-ordinated reflex activity is elicited so that the distension of the detrusor which initiates its con traction (the micturition reflex) is accompanied by relaxation of the striated muscles of the urethra The micturition reflex has its afferent and efferent pathways in the pel vic nerves (S 2 S 4) while the relaxation of the urethral striated muscles is brought about through pelvic afferents and pudendal efferents The co-ordination of afferent and efferent impulses of both autonomic and somatic systems at conscious and sub conscious levels is responsible for the ability of the adult human to inhibit and initiate voiding irrespective of the degree of bladder filling Receptors in the bladder mucosa are able to recognize painful but not tactile stimulation The afferent pathways mediat ing pain impulses from the bladder have not been established with certainty The de-

Table I Patients subjected to Clinical Studies of Urogenital and Anorectal Function
The investigations performed in each patient are indicated
Ur = urological study Sex = study of sexual function An = anorectal study Investigation performed +
not performed −

Patient no	Sacral nerves divided R	Sacral nerves divided L	Diagnosis	Age at op	Sex	INVESTIGATIONS Ur	Postop. time	Sex	Postop time	An	Postop. time
1	4 5	4 5	Chordoma	61	F	+	5 3/12	+	5 9/12	−	
2	3,4 5	3,4 5	Gangl oneuroma	20	F	+	5 6/12	+	6 7/12	−	
3	3 4 5	3 4 5	Chordoma	68	F	+	1 6/12	+	2 2/12	+	2 2/12
4	3 4,5	2 3,4 5	Chordoma	67	M	+	1 8/12	+	2 9/12	+	2 8/12
5	2 3 4 5	2 3,4 5	Chordoma	57	M	+	1 2/12	+	3 6/12	−	
6	2 3 4 5	2 3 4 5	Chordoma	64	F	−		−		+	6/12
7		2 3,4 5	Chondromyxoid fibroma	21	M	+	4/12	+	11/12	+	11/12
8	1,2 3 4 5		Malignant Schwannoma	28	M	+	5/12	+	2 2/12	+	1 2/12
9		1 2 3 4 5	Giant cell tumor	34	F	+	1 10/12	+	2 6/12	+	2 6/12
10		1 2 3,4 5	Fibrosarcoma	42	M	+	3 6/12	+	4 7/12	+	4 7/12

into the rectum causes sensory stimulation in the rectum and upper part of the anal canal (afferent fibres in the pelvic and pudendal nerves, S 2 S 4) In response to the rectal distension the internal anal sphincter relaxes reflexively (pathways most probably intramural), and a reflex contraction of the external anal sphincter is elicited (afferent pathways in the pelvic nerves and efferent in the pudendal nerves) If the fæces entering the rectum are small the basal activity of the sphincters is restored and the individual is no longer conscious of the contents in the ampulla. Further filling of the rectum evokes stronger sensory stimulation experienced as a need to defæcate Eventually the internal sphincter becomes constantly relaxed and the basal activity of the external sphincter is depressed leaving voluntarily induced contraction responsible for the closure of the anal canal The closure of the anal canal permits build up pressures within the rectum so that subsequent sphincteric inhibition results in expulsion of stools, facilitated by rectal contraction (efferent fibres in the pelvic nerves) When emptying is complete a rebound contraction of the anal sphincters occurs

MATERIAL

Altogether ten patients were studied six with bilateral and four with unilateral sacrifice of sacral nerves (Table I) The nerves were identified and cut during operations for radical extirpation of tumours in the sacrum or its vicinity In no patient has any sign of local tumour recurrence been observed

Studies of urinary and sexual function were carried out in nine patients and studies of anorectal function in seven Details of diagnosis sex age investigations performed and postoperative time in years are given in Table I

METHODS

Urinary function (I)

After taking the patient s history the following studies were carried out clinical examination, cystometry cystoscopy including testing of the sensibility of the bladder and urethra, intravenous pyelography and urinary culture

For cystometry two plastic catheters (sonde a nutrition K 32 no 5 Fr Pharmaseal) were introduced into the bladder through the urethra. Isotonic saline at room temperature was infused at a rate of about 50 ml per min through one of the catheters. The other catheter was connected via a pressure receptor and an amplifier to a kymograph (Mingograf, Elema Schonander) providing a continuous recording of the intravesical pressure The pressure receptor was placed at a level of 5 cm below the pubic symphysis to avoid negative pressure recordings. The intrarectal pressure was recorded

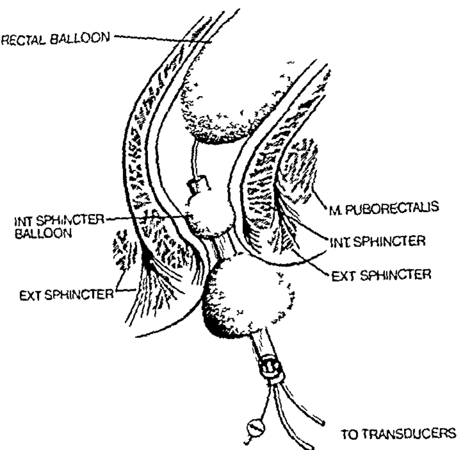


Fig. 1 Schematic drawing of the pressure-sensing device in the rectum and the anal canal. Distension of the rectal balloon provides the stimulus for reflex responses from the internal and external sphincters. Separate pressures are obtained from the rectal balloon and the internal sphincter balloon. The external balloon was used as an aid to keep the device in place.

continuously via a balloon catheter Thus pressure was electronically subtracted from the intravesical pressure The pressure increase caused by an intra abdominal pressure increase was thereby eliminated, and in the subtraction curve the »true» intravesical pressure was recorded Early during bladder filling the calibration of the rectal pressure was changed so as to give an exact elimination in the subtraction curve of a press ure increase caused by straining Thus the numerical value of the rectal pressure cannot be considered as correct

The sensibility of the bladder mucosa was tested only by electrocoagulation in the patients with bilateral loss of sacral nerves In the patients with unilateral loss of sacral nerves a more elaborate investigation of the sensibility of the bladder mucosa was performed Thus, the sensibility of the mucosa was tested by electrocoagulation light touch with a ureteral catheter and by forcing the catheter more vigorously against the bladder wall When thermæsthesia was tested the bladder was filled with 200 300 ml of physiological saline at room temperature Then 10 15 ml saline at 0°C or +60°C was injected as a jet against the bladder wall through a ureteral catheter with an end hole, introduced into the bladder through a cystoscope In all patients the sensibility of the urethra was tested only by pin pricking

Sexual function (II)

The history was taken by personal interview and a questionnaire Skin sensibility and the sensibility of the glans penis were tested by touching with cotton wool and pin pricking The male patients except for one who refused were also submitted to an electromyographic investigation in attempt to record myoelectric signals from the external urethral and anal sphincters during ejaculation

For the electromyographic study the patient was placed in a modified lithotomy position after having emptied his bladder Co axial needle electrodes of 0 5 mm external diameter were inserted percutaneously into the striated urethral and anal sphincters according to a technique described previously (Petersén and Stener 1970) The positioning of the needles was monitored by an oscilloscope and a loud speaker connected to the electromyograph A three channel type Disa electromyograph was used for the registration When the electrodes were in place the subject was left in solitude to bring about ejaculation by masturbation Of the four patients investigated only one could bring about ejaculation (no 8) The electromyographic investigation was not repeated in the failure cases

Anorectal function (III)

The history was taken The sphincter tone was estimated by palpation The anal reflex (contraction of the anal sphincter on drawing a needle across the perianal skin) was

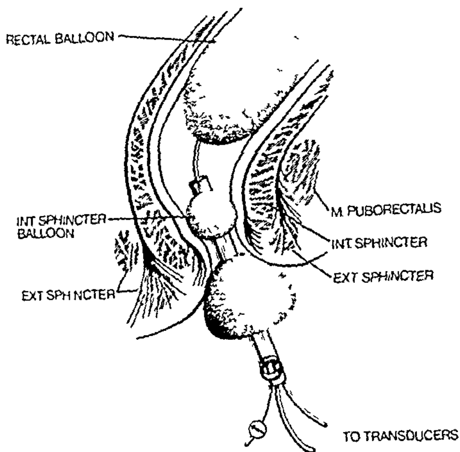


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sensation could not be obtained the balloon was filled with a maximum of 500 ml. The rectal balloon was then emptied in the same stepwise manner During the whole procedure pressure recordings from the rectal balloon and the balloon placed in the anal canal were made as well as electromyograms from the external anal sphincter Pressure/volume curves (rectometrograms) were constructed for each patient. This was done by subtracting the pressures of the rectal balloon obtained at various volumes in free air from the pressures obtained at the same volumes with the balloon in the ampulla recti as described by Ihre (1974)

RESULTS

Bilateral loss of sacral nerves (I II III)

S4 S5

This patient (no 1) had slight urinary stress incontinence and used a diaper Cystometry revealed detrusor activity She had no residual urine Cystoscopic findings were normal as also were sensibility tests of the bladder and urethra. The pyelogram was without pathological changes. Urinary culture was positive (>100 000 bacteria/ml).

The patient considered her sexual function to be normal and enjoyed sexual intercourse regularly She had not experienced any postoperative change of sexual perception or orgasm. The sensibility of the labiae was normal.

In this patient the rectum had been exstirpated

S3 S4 S5

Of these two women one had an indwelling catheter (Patient no 3). The other had to strain to empty her bladder No micturition contraction was recorded in the cystometrograms. The residual urine volume was 90 ml in the patient without a catheter Cystoscopy revealed slight trabeculation Painful stimuli to the *mucosa of the bladder and* urethra were not perceived The pyelograms were normal One of these patients had a urinary tract infection (no 3).

The younger of these two patients (no 2) reported no change of sexual behaviour or perception postoperatively and considered her sexual function to be normal. The older patient had all her life experienced minimal perception upon sexual stimulation but still had intercourse although unfrequently She did not *recognize any alteration post*operatively The sensibility of the labiae was normal in these two patients.

Anorectal function was studied in the older patient (no 3). She had no sense of defecatory need Soiling occurred *The patient used laxatives* and visited the toilet every

tested bilaterally by observation The sensibility of the anal canal, below the dentate line, and perianal skin was tested by tactile, painful and thermal stimuli The rectum and internal anal sphincter were investigated with a pressure recording device (Fig. 1) suggested by Schuster et al (1965) Electromyography of the external anal sphincter was made on both the left and the right side simultaneously with the pressure recordings Thus, the relationships between rectal volumes and pressures pressure changes in the internal sphincter region and the myoelectric activity in the external sphincter were established

The pressure recording device consisted of a hollow metal cylinder (external diameter 7 mm) with two surrounding balloons approximately 1 cm apart The inner somewhat smaller balloon was connected via polyethylene tubing to a pressure recording unit (Grass Model 7 B Polygraph paper speed used 50 mm per min) while the outer balloon was used to keep the device in place A third balloon of thin latex (5 cm long 2 cm wide when inflated with 10 ml of water) was inserted through the hollow core of the recording device and was also connected via polyethylene tubing to the pressure recording unit The pressure receptor was placed at the level of the anal orifice
The myoelectric activity of the external anal sphincter was picked up by concentric needle electrodes (Disa) of 0 65 mm diameter The signals were amplified on a Disa electromyograph and recorded on tape using an FM tape recorder (Philips Ana log 7) Graphic recordings were obtained by means of an ink jet recorder (Mingograf Siemens-Elema) at a reduced tape speed playback The quantitative signal analysis was performed on an analyzer (Örtengren 1975) entailing continuous recordings of the fullwave rectified and smoothed, »integrated» total signal The output from the detector was presented on a logarithmic decibel scale with arbitrary reference

Procedure

The needle electrodes were placed bilaterally in the external anal sphincter with the patients in the lithotomy position Recordings were made of the spontaneous myoelectric activity during voluntary contraction of the sphincter and during coughing The thin latex balloon was then placed in the ampulla recti and the hollow metal cylinder with its two surrounding balloons was inserted into the anal canal so that the internal balloon when inflated with 4 ml of water (+37°C) was surrounded by the internal anal sphincter The external balloon used for keeping the device in place, was inflated with 15 ml of air The rectal balloon was straightened out by filling it with a small volume of water which was then removed The registrations then started and the rectal balloon was filled with 20 ml of water (+37°C) followed by a further 30 ml after approximately 30 seconds. The rectal balloon was then intermittently filled with 50 ml of water every 30 60 seconds until the patient reported an almost intolerable sensation, i e the maximum tolerable volume was reached In cases in which such a

S2 S3 S4 S5

Urinary function was studied in the male patient (no 5) He had undergone a transurethral bladder neck resection postoperatively He was incontinent and wore an incontinence bag and had to strain when he wished to empty his bladder No micturition contraction was observed in his cystometrogram. Residual urine was 50 ml Cystoscopy revealed trabeculation There was loss of bladder and urethral sensibility Pyelography was normal Urinary culture was positive

Sexual function in this man was impaired He had weakened libido but enjoyed sexual intercourse a few times a month. Erection occurred exclusively upon psychical stimulation and was somewhat weaker than preoperatively but sufficient to permit intercourse »Ejaculation» was of a dripping nature The sensation of orgasm was altered and not referred to the penis and perineum as it had been before the onset of the tumour disease The penis and glans were anæsthetic

Anorectal function was studied in the female patient (no 6). She was incontinent and constipation was her only safeguard against soiling. Defaecatory need was not experienced normally and she was unable to recognize faecal quality in the anal canal Sphincter tone was lacking on palpation The anal reflex was not observed The anal region was anesthetic The patient became aware of rectal distension at volumes of 300 ml (71 mm Hg) and when the rectal balloon had been filled to 400 ml or more it tended to protrude outside the anus without the patient being conscious of this. The internal anal sphincter reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at a volume of 250 ml (50 mm Hg). Electromyograms from the external anal sphincter displayed denervation potentials only No external anal inflation reflex could be observed nor was there any voluntarily induced myoelectric activity

Unilateral loss of sacral nerves (I II III)

S2 S3 S4 S5 and S1 S2 S3 S4 S5

Essentially the same findings were recorded in these four patients. Their urinary function was subjectively unimpaired Micturition contractions were registered in the cystometrograms although the patients had to strain at the end of micturition. The residual volumes were 10 15 ml The cystoscopy findings were essentially normal. Bladder wall sensibility tests revealed that light touch with a ureteral catheter could not be felt on either side When the catheter was forced more vigorously against the bladder wall this caused pain on the intact side and diffuse discomfort on the other side in the latter case with poor ability of lateralization. When testing the thermaesthesia, the jets of cold or hot saline were correctly recognized on the intact side but could not be felt on the denervated side Coagulation of the mucosa of the bladder and trigone was felt as

day at the same time to evacuate her rectum She needed a diaper Sphincter tone judg ed by palpation was decreased The anal reflex was absent. The sensibility of the anal region was decreased with respect to tactile and painful stimulation, and lacking as re gards thermal stimulation The patient became continuously conscious of rectal distension at a volume of 350 ml (87 mm Hg) The rectum had a maximum tolerable vol ume of at least 500 ml (>105 mm Hg) She felt a dull uncomfortable sensation in the lower abdomen at these substantial rectal volumes The internal anal sphincter reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at a volume of 200 ml (46 mm Hg) EMG revealed weak spontaneous activi ty in the external anal sphincter Attempts to contract the sphincter voluntarily result ed in a small increase of the myoelectric activity Denervation potentials were record ed in the electromyogram The external anal inflation reflex (transient contraction of the external anal sphincter at rectal distension) was not observed The weak sponta neous myoelectric discharge disappeared at a rectal volume of 400 ml (105 mm Hg)

Right side S 3 S 4 S 5 Left side S 2 S 3, S 4 S 5

This patient (no 4) had urinary stress incontinence He wore a diaper and had to strain when he wished to empty his bladder No micturition contraction was observed in his cystometrogram The residual urine volume was 15 ml Cystoscopy revealed trabecul ation of the bladder wall Bladder wall sensibility was absent Pyelography was normal Urinary culture was negative

Sexual function was altered postoperatively Libido was preserved but erection weaken ed and insufficient for intercourse Ejaculation occurred nightly with an orgasm like sensation The sensibility of the left side of the penis and glans was heavily diminished

There was fæcal incontinence if rectal contents were not solid Defæcatory need was never experienced as it had been preoperatively The patient was unable to discriminate between different qualities of rectal contents at defæcation which was brought about by straining or by pressure on the rectum from behind Sphincter tone judged by pal pation was decreased The anal reflex was absent The sensibility of the anal region was abolished concerning all modalities on the left side and the posterior quadrant of the right side, it was weak on the anterior quadrant of the right side The patient became continuously conscious of rectal distension at a volume of 300 ml (32 mm Hg) and had a maximum tolerable volume of at least 500 ml (60 mm Hg) The internal anal sphinct er reacted with transient relaxations on stepwise rectal balloon filling and became con tinuously depressed at a volume of 300 ml (32 mm Hg) The external sphincter display ed weak spontaneous myoelectric activity bilaterally and presence of denervation potentials A small increase of the myoelectric activity was recorded on voluntary con traction bilaterally The external anal inflation reflex was absent. The weak spontaneous discharge decreased but did not disappear as the rectum was progressively distended

S2 S3 S4 S5

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pain on the intact side On the denervated side such stimuli were not felt in the bladder, nor was pin pricking felt in the urethra. Pyelography was normal except in Patient no 8 who had right sided hydronephrosis and hydroureter owing to postoperative fibrosis This patient was later operated upon with reimplantation of the right ureter into the bladder Urinary culture was positive in Patient no 9

The sexual function of these patients was subjectively unimpaired The quality and degree of the reactions of the external genitalia was unchanged as also was the degree of sexual satisfaction There was loss of sensibility on the denervated side of the penis and labiæ EMG was recorded from the external urethral and anal sphincters in one of the male patients (no 8) during ejaculation Clonic contractions of both sphincters occurred alternately

The anorectal function was also subjectively unimpaired and ability to recognize different qualities of rectal contents in the anal canal was present Sphincter tone judged by palpation was normal The anal reflex could be elicited on the intact side but not on the denervated side The sensibility of the anal region was unimpaired on the intact side but there was anæsthesia concerning tactile and thermal stimuli on the denervated side Painful stimuli on this side were recognized as a weak unpleasant sensation localized to the midline or intact side The patients became continuously conscious of rectal distension at volumes of 150 200 ml (18 34 mm Hg) and had maximum tolerable volumes of 200 350 ml (36 52 mm Hg) The internal sphincters reacted with transient relaxations on stepwise rectal balloon filling and became continuously depressed at rectal volumes of 100 200 ml (18 43 mm Hg) The external anal sphincter displayed spontaneous myoelectric activity bilaterally and there was strong increase of this activity bilaterally on voluntary contraction During prolonged contraction (about 30 seconds) the strongly increased activity was maintained bilaterally The external anal inflation reflex was observed bilaterally in three of these patients, in one (no 10) the presence of the reflex was doubtful Reflex decrease or inhibition of external sphincter activity was recorded at maximum tolerable volumes

DISCUSSION

Bladder and urethra

The micturition reflex in the cystometrogram was not abolished by sacrifice of the fourth and fifth sacral nerves bilaterally but it was abolished if the third sacral nerves were sacrificed as well This indicates that the second sacral segment alone cannot subserve the micturition reflex and is in accordance with the observations of Markland et al (1972) that the main motor axons of the pelvic parasympathetic nerves arise in the third and fourth sacral segments. The cystometrograms of the patients with unilateral

sacral denervation revealed detrusor activity although these patients had to strain toward the end of micturition in order to empty their bladders. This is in agreement with the findings of several authors who in patients with lumbosacral dysraphic states with *unilateral neurological impairment* found normal bladder function (e g Ericsson et al. 1970)

The unilaterally denervated patients offered a unique possibility to investigate unsettled questions concerning bladder sensibility Thus detrusor mucosal pain is said to be mediated by spinal segments as high up as the L 1 to T 12 levels (Bors and Comarr 1971) Our patients with unilateral sacral denervation were unable to feel pain on the denervated side when the bladder mucosa was electrocoagulated They could however feel stretching of the bladder wall on the denervated side which is in agreement with the findings of Talaat (1937) who recorded afferent impulses from the hypogastric nerves upon distension of the bladder in dogs Several authors (Senger and Rothfeld 1947 Nathan 1952 Bors et al 1956) have found no thermæsthesia of the bladder mucosa and state that this sense is confined to the urethra. Pitfalls in the investigation of bladder thermæsthesia and the ability to lateralize thermal stimuli are first ly that temperature changes of the cystoscope or of the whole bladder content may be mediated via urethral nerves secondly that the stimulus might induce local detrusor contraction making it possible to lateralize it and thirdly that the jet of hot or cold saline might evoke the lateralized sensation purely by mechanical stimulation of receptors. However with the latter technique used in the present study (I) the differentiation of heat and cold and the ability to lateralize must have been conveyed in nerves from the bladder mucosa since the unilaterally denervated patients could not feel thermal stimuli at all on the denervated side of the bladder but could recognize heat and cold on the intact side Moreover the jet was not felt on either side when the injection was made with saline at room temperature with the same force on both sides. The experiments thus indicate that the bladder mucosa has thermæsthesia which is most probably conveyed by the parasympathetic pelvic nerves. This is in agreement with the findings of e g Ray and Neill (1947) Retief (1950) and McDonald and Murphy (1959) *Thermæsthesia seems however less well developed in the bladder mucosa than in the skin or oral mucosa, which might account for the divergent findings of different investigators*

Genitalia

The sexual function was unaltered in the three women with bilateral loss of the fourth and fifth or third fourth and fifth sacral nerves. The sensibility of the labiae appears to be mediated above the level of S 3 since both the patients who lacked the third sacral nerves had normal sensibility The sensibility of the penis seems to be subserved mainly by the second sacral nerve Patient no. 4 had normal sensibility on the right side

of the penis where this nerve had been spared, but strongly diminished sensibility on the left side where only the first sacral nerve was left Patient no 5 who lacked the second sacral nerve on both sides had an anæsthetic penis. This is in agreement with the findings of Bohm et al (1956) who found unilateral impairment of cutaneous sensibility of the penis after selective sectioning of one dorsal root of S 2 performed in seven men

In the male, the preservation of only the first sacral nerve on both sides is compatible with sexual activity such as reported by Patient no 5, who had exclusively psychogenic erection, dripping »ejaculation», and orgasmic sensation referred to the lower abdomen This case parallels one reported by Bernhardt (1888) who described the same condition in a young man with a traumatic lesion of the spinal cord with anæsthesia of the four lower sacral dermatomes Purely psychogenic erections are known to occur in about 30 per cent of paraplegics with lower motor neuron lesions (Bors and Comarr 1960)

In the patients with total loss of sacral nerves on one side the sex act was experienced as essentially unaltered although there was unilateral anæsthesia of the penis or labiæ The EMG from Patient no 8 during ejaculation displayed the normal event of clonic contraction bilaterally of the external urethral and anal sphincters (Petersén and Stener 1970), although the contractions of the two sphincters alternated which is not the case in normal subjects We can offer no explanation of this phenomenon in our patient

Rectum and anus

Normal anorectal function, like normal bladder function appears to be dependent on the preservation of at least one third sacral nerve as the patients who lacked this nerve on both sides were incontinent with respect to soft fæces Moreover these patients had difficulty in expelling solid stools When the second sacral nerve had been spared painful and tactile stimuli could be weakly perceived in the anal canal This sensibility of the anal canal however was not sufficient for recognition of the quality of stools passing the canal The sensory perceptions from the anal canal thus seem to be mediated mainly in nerves below the S 2 level The patient with only the first sacral nerves left bilaterally was anæsthetic in the anal region

There was also impaired sensibility concerning rectal wall distension in the three patients with bilateral loss of sacral nerves and it may be concluded that the sensation of rectal wall distension is also to a large extent mediated via segments below the S 2 level

In all seven patients who where subjected to the study of anorectal function, the internal anal sphincter displayed the normal events of relaxation as the rectum was distended – the internal anal inflation reflex – indicating that this is not a spinal reflex at the S 2 S 5 levels. Denny Brown and Robertson (1935) have reported the presence of this internal sphincter reflex in a patient with destruction of the sacral cord and in another patient with sectioned hypogastric nerves. The pathways of the reflex are unknown but an intact anorectum seems necessary (Gaston 1948 Schuster et al. 1963) Several authors (e g. Denny Brown and Robertson 1935 Schuster 1975) have suggested an intramural pathway which is well compatible with our findings.

The external anal sphincter also seems to be dependent to a large extent on the preservation of sacral nerves below the S 2 level as the spontaneous myoelectric activity of this sphincter was weak in Patient no 3 who had the second sacral nerve left on both sides, and in Patient no 4 who had this nerve left on one side In addition denervation potentials were registered in these patients. In Patient no 6 who had only the first sacral nerves left no spontaneous activity was present in the external sphincter except for a few denervation potentials A small increase of the myoelectric activity during attempts to contract the sphincter voluntarily was seen in the patients who had one or both second sacral nerves left This weak sphincter contraction was, however without obvious significance for the anorectal function No transient reflex contraction of the external sphincter during rectal wall distension – the external anal inflation reflex – was observed in the patients with bilateral nerve sacrifice indicating that this reflex is mediated below the S 2 level
Unilateral sacral denervation did not imply any significant impairment of anorectal function There was however a loss of sensibility on the denervated side although this was of no significance for recognizing the quality of the rectal contents when they passed the anal canal The sense of rectal distension seemed normal as also did the reflex pattern of the internal anal sphincter The spontaneous activity of the external anal sphincter was of good quality bilaterally but in some of the electromyograms a slight difference of activity between intact and denervated sides could be observed On brisk voluntary contraction there was an essentially normal increase of myoelectric activity bilaterally and this increased activity could be maintained on prolonged voluntary contraction as may be expected in normal subjects (Kadefors and Petersén 1970). This strongly suggests an overlap distribution of motor fibres from the right and left pudendal nerves and proves the sufficiency of only unilateral innervation of the external anal sphincter The investigations of Sherrington (1892) and Bishop (1959), who in animals produced contraction of the entire anal circumference with unilateral pudendal nerve stimulation were thus confirmed

Several different aspects of anorectal function were studied. The significance of any of these factors per se for continence or defecation, however can not be evaluated

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Several different aspects of anorectal function were studied. The significance of any of these factors per se for continence or defæcation however can not be evaluated

Even though the internal anal sphincter had a normal reflex pattern in all patients the power of this sphincter cannot be judged It might well be that, at least in the patients with bilateral loss of sacral nerves, it had a weaker tone than ordinarily but still had the capacity to relax All other factors studied were negatively affected in this group of patients In spite of this heavily impaired anorectal function the patients managed astonishingly well with the help of diapers, constipating diet and regular bowel care

BIOMECHANICAL STUDY OF PELVIC STRENGTH (IV)

MATERIAL

Fifteen cadaver pelvises were studied They consisted of the pelvic ring with the fifth lumbar vertebra and were roughly cleaned from soft tissues except for the ligaments which were left intact The specimens were kept in deep freeze and allowed to thaw at room temperature in moist wrappings 12 24 hours before testing The pelvises were divided into three groups with five specimens in each In the first group no resection was made In the second group sacroiliac resection was performed according to alter native A (see below) and in the third according to alternative B (see below) The speci mens originated from patients who had died of diseases that did not directly engage the skeleton Cardiovascular diseases dominated the causes of death The age distribu tion was fairly wide 29 85 years, but the age compositions of the different groups were quite similar Two cases of uraemia were included (unresected group and group A) and one patient had steroid treatment during the last 6 months before death (un resected group). It was not possible to establish the exact duration of premortal bed rest from the medical records. A major difference in this respect between the different groups was however not likely

Resection A

The resection is illustrated in Figure 2 darkest fields.

Anteriorly the resection comprised the whole of the sacrum except for the first seg ment Thus the resection line ran between the bodies of S 1 and S 2 and through the anterior opening of the first sacral holes. Posteriorly the resection also comprised parts of the first sacral segment, including the posterior opening of the first sacral holes and the entire posterior wall of the sacral canal. From each iliac bone a posterior part ad jacent to the resected portion of the sacrum, was included. In this manner about one-third of the sacroiliac joint with corresponding ligaments was removed on both sides.

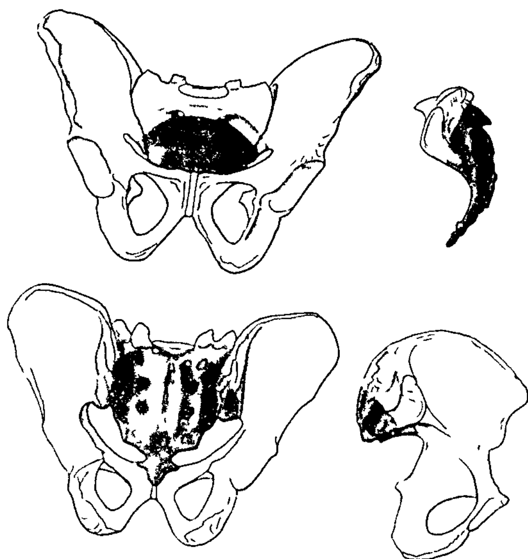


Fig 2 Schematic drawing of resections performed in the biomechanical study on pelvic strength (IV)
Resection A Darkest fields.
Resection B Less dark fields also included.

Resection B

The resection is illustrated in Figure 2 less dark fields also included

Anteriorly the first sacral segment was divided about one centimetre below the promontory and the resection line ran superior to the first sacral holes. Posteriorly the body of S 1 was d v d d only a few millimetres from the lumbosacral disc A considerably larger part of each iliac bone than in Resection A was included so that only about half the sacroiliac joint with corresponding ligaments remained on each side

METHOD AND CALCULATIONS

The ischial tuberosities and the inferior pubic rami of the pelvises were fixed in epoxy resin (Plastic Padding®) in a metal box in a position corresponding to upright standing (Boyd et al 1958) The specimens were loaded on the L 5 vertebra in a standard material testing machine (Alwetron Model T 2000) with a deformation speed of 5 mm/min. A strain gauge load cell transducer of 9810 N (1000 kp) with an accuracy of ± 1 % was used The load and the time were registered on an x y recorder over a measuring bridge and an amplifier The specimens were x rayed before and after testing.

To make it possible to judge the clinical significance of the experimental data the hypothetical loads in upright standing were calculated according to Nachemson and Elfstrom (1970) who have shown that the load on lumbar discs in upright standing may be calculated with the formula $P = 6 + 2\ 2\ W$ where W is the part of the body weight exerting load upon the disc This has been estimated by Ruff (1950) who found that approximately 60 per cent of the body weight lies above L 5

Prior to failure testing two specimens in each group were loaded one to three times up to approximately twice the estimated normal load in upright standing to find out whether any permanent tissue damage occurred at these loads Eventually all specimens were subjected to ultimate compressive loads

RESULTS

The preliminary tests with loading to approximately twice the estimated normal load in upright standing did not show any significant residual deformation

In the test to failure the mean ultimate compressive load in the group of unresected pelvises was 4856 N (standard deviation 824 N) The specimens resected according to A had a mean ultimate compressive load of 3286 N (standard deviation 1971 N) and those according to B 2484 N (standard deviation 1500 N)

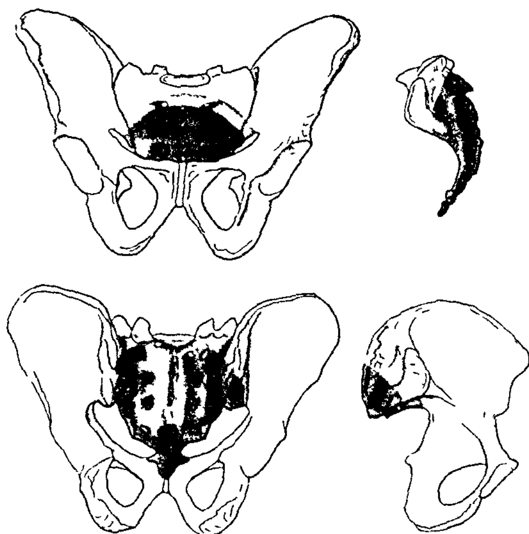


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Resection A Darkest fields.
Resection B Less dark fields also included.

strength was 4 8 times the calculated load in upright standing in the unresected group 1.5 5 times after resection between S 1 and S 2 and about twice the calculated load after resection through S 1

From this study it seems safe with regard to residual strength of the pelvic ring to allow patients to stand and walk with full weight bearing at an early stage postoperatively after submaximal resection of the sacrum including adjacent iliac bone

All specimens fractured through the lateral parts of the sacrum relatively close to the sacroiliac joints, first on one side and then on the other The fracture localization was difficult to observe in the specimens after deloading when the sacrum returned almost to its original position due to the elasticity of the obviously uninjured sacroiliac ligaments If the deformation was allowed to continue well past the point of failure the injuries became more obvious and in resected specimens the S 1 vertebra or its remains eventually split Permanent dislocation of the sacroiliac joints did not occur in any specimen

DISCUSSION

The small number of specimens makes statistical evaluations unwarrented Tendencies can however, be recognized It cannot be excluded that biological and other factors had influenced the specimens in a negative direction to weaken their strength. This would, however be no disadvantage in this investigation as the safety margin concerning pelvic strength after major sacral resection would then in reality be greater than is shown by the study

A slow deformation speed (5 mm/min) was chosen mainly to make it possible to follow the deformation and terminal failure of the specimens visually Resistance to loading is lower when testing with low speeds than with high speeds (McElhaney 1966) Thus, the low testing speed might also have contributed to the registered ultimate compressive load values being minimum values

The sacroiliac junction is very strong Thus the failure occurred in the lateral parts of the sacrum in unresected as well as resected specimens and the deformation curves also indicated a very low degree of permanent deformation of the soft tissues.

In this limited material the weakening of the sacroiliac region after resection according to A was approximately 30 per cent and after resection according to B approximately 50 per cent, as calculated from the mean values Information on the normal load in vivo on the pelvic ring is needed to evaluate our results and to judge whether the resections leave sufficient residual strength in the pelvic ring to allow early postoperative weight bearing. It should be borne in mind that the load at a certain vertebral level because of muscular activity is greater than the weight of the overlying part of the body Nachemson and Elfström (1970) have shown that the load varies depending on posture, movements, etc ordinary slow walking increases the load by about 15 per cent jumping on the floor and coughing by about 40 per cent straining with erect posture by about 50 per cent and straining when seated by 5 35 per cent In the cases in which information on the body weight was available (11/15) a good margin was found between the calculated load in upright standing and the load at failure Thus the test

Anorectal function was impaired when only the first and second sacral nerves had been spared (No patient with preservation of the third sacral nerves was studied) Soiling occurred and the sensation of rectal distension was defect as also was the sensibility of the anal canal. The internal anal sphincter displayed the normal reflex pattern even when only the first sacral nerves had been spared There was weak spontaneous and voluntary myoelectric activity in the external anal sphincter when only the first and second sacral nerves were intact and no activity at all except for denervation potentials when only the first sacral nerves had been preserved

In patients with unilateral loss of sacral nerves the *micturition reflex* was present even in those with total unilateral sacral denervation The bladder mucosa was anæsthetic on the denervated side but the presence of pain and thermal sensibility was demonstrated on the intact side

Sexual function was subjectively unimpaired in patients with total unilateral sacral denervation In one patient the normal clonic contractions of the striated urethral and anal sphincters during ejaculation were recorded electromyographically although the contractions of the two sphincters alternated for some reason. The penis or labiæ were unilaterally anæsthetic when the lower four or all sacral nerves had been sacrificed

Anorectal function was subjectively unimpaired One sided sacral denervation implied deficient sensibility of the anal canal unilaterally but no disturbance of sphincter function

The **BIOMECHANICAL STUDY** was performed as vertical loading tests on the L 5 vertebra of 15 pelvic specimens divided into three groups, one with no resection, one with resection of the sacrum between the first and second segments and one with resection through the first segment approximately 1 cm below the promontory The resections also comprised substantial parts of the adjacent iliac bones. As calculated by mean values the approximate weakening of the pelvic ring by resection between S 1 and S 2 was 30 per cent and by resection through S 1 50 per cent To make it possible to judge the clinical significance of the experimental data the hypothetical loads in upright standing were calculated according to Nachemson and Elfstrom (1970) There appeared to be a reasonable safety margin between the calculated loads and the loads at failure This margin was about 4 8 times the calculated load in upright standing in the unresected group 1 5 5 times after resection between S 1 and S 2 and about twice the calculated load after resection through S 1

IN CONCLUSION it seems necessary to spare at least one and perhaps both third sacral nerves in order to preserve normal bladder and anorectal function. The patients with bilateral loss of the lower three or four sacral nerves seemed however in spite of the loss of normal bladder and bowel control to manage astonishingly well with the

SUMMARY AND CONCLUSIONS

The purpose of this work was to study the clinical effects of major resection of the sacrum, with well-defined sacrifice of sacral nerves, concerning urogenital and ano rectal function Moreover, an answer was sought to the question what residual strength and safety margin are retained in the pelvic ring after major amputation of the sac rum

The **CLINICAL STUDIES** were performed in altogether 10 patients in whom sacral nerves had been sacrificed during surgical procedures for radical removal of tumours Six patients had **bilateral** loss of sacral nerves (5 took part in the urogenital and 3 in the anorectal studies) and 4 had **unilateral** loss of sacral nerves (all took part in both the urogenital and anorectal studies)

Urinary function was studied by history clinical evaluation, cystometry and cysto scopy including a test of vesical and urethral sensibility with different stimuli *Sexual function* was evaluated by history, and one patient with total unilateral sacral denerv ation was subjected to an electromyographic study of the external urethral and anal sphincters during ejaculation *Anorectal function* was studied by history clinical evalu ation and simultaneous recordings of volume and pressure in the rectal ampulla press-ure changes in the internal anal sphincter region and the myoelectric activity in the external anal sphincter

In patients with **bilateral loss of sacral nerves** there was no active *detrusor contraction* when only the first and second sacral nerves had been spared indicating that segments below the S 2 level are essential for the micturition reflex This reflex was present when the third sacral nerves had been spared besides the first and second There was loss of bladder mucosal pain when the lower three sacral nerves had been sacrificed

Sexual function seemed unimpaired in women with preservation of only the first and second sacral nerves A man with only the first sacral nerves spared had regular sexual intercourse but purely psychogenic erection dripping »ejaculation» and a somewhat altered sensation of orgasm. The sensibility of the labiæ and penis seemed to be medi ated mainly in the second sacral nerves.

Anorectal function was impaired when only the first and second sacral nerves had been spared (No patient with preservation of the third sacral nerves was studied) Soiling occurred and the sensation of rectal distension was defect as also was the sensibility of the anal canal The internal anal sphincter displayed the normal reflex pattern even when only the first sacral nerves had been spared There was weak spontaneous and voluntary myoelectric activity in the external anal sphincter when only the first and second sacral nerves were intact and no activity at all except for denervation poten tials when only the first sacral nerves had been preserved

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IN CONCLUSION it seems necessary to spare at least one and perhaps both third sac- ral nerves in order to preserve normal bladder and anorectal function. The patients with bilateral loss of the lower three or four sacral nerves seemed however in spite of the loss of normal bladder and bowel control to manage astonishingly well with the

help of diapers incontinence bags constipating diet and regular toilet visits. Sexual function in women is probably unimpaired by bilateral sacrifice of the three lower sacral nerves In the male the preservation of only the first sacral nerves is, at least in occasional cases compatible with sexual activity and intercourse, the stimuli being purely psychogenic Total unilateral sacral denervation leads to no significant impairment of urogenital or anorectal function

A submaximal sacral amputation, including adjacent iliac bone on both sides, seems not to imply any great risk for failure of the pelvic ring even if the patient is allowed to stand and walk with full weight bearing at an early stage postoperatively

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REFERENCES

BERNHARDT, M (1888) Klinischer Beitrag zur Lehre von der Innervation der Blase des Mastdarmes und der Geschlechtsfunktion (beim Manne) Berlin Klin Wschr 25, 637 640

BISHOP, B (1959) Reflex activity of external anal sphincter of cat J Neurophysiol 22 679 692

BOHM, E , FRANKSSON C , PETERSEN, I (1956) Sacral rhizopathies and sacral root syndromes (S II S V) Acta chir scand Suppl 216

BORS, E , MA, K.T , PARKER R.B (1956) Observations on some modalities of bladder sensation J Urol 76, 566 575

BORS E & COMARR, A.E (1960) Neurological disturbances of sexual function with special reference to 529 patients with spinal cord injury Urol Surv 10 191 222

BORS, E. & COMARR, A E (1971) Neurological urology S Karger AG, Basel

BOWERS R.F (1948) Giant cell tumor of the sacrum a case report Ann Surg 128 1164 1172

BOYD, J D et al (1958) Textbook of human anatomy 1st ed , reprinted MacMillan and Comp Ltd , London

CARLSSON, C A & SUNDIN T (1974) Neurogena blåsrubbningar Elanders Boktryckeri AB Kungsbacka

DENNY BROWN D & ROBERTSON, E.G G (1935) An investigation of the nervous control of defæcation Brain 58 256 310

DUTHIE H L (1971) Anal continence Gut 12 844 852

ERICSSON N O HELLSTRÖM B NERGÅRDH A. & RUDHE, U (1970) Unilateral neurological defect in myelomeningocele with normal bladder function Acta pædiat scand 59 487 490

FREIER D T STANLEY J C & THOMPSON, N W (1971) Retrorectal tumors in adults Surg Gynec Obstet 132 681 686

GASTON, E A (1948) Fecal continence following resections of various portions of the rectum with preservation of the anal sphincters. Surg Gynec Obstet 87 669 678

HAYS, R.P (1953) Resection of the sacrum for benign giant cell tumor a case report Ann Surg 138, 115 120

HOTCHKISS R.S. (1970) Physiology of the male genital system as related to reproduction In Urology 3rd ed Vol 1 Saunders Comp Philadelphia, London Toronto

IHRE T (1974) Studies on anal function in incontinent patients. Scandinavian Journal of Gastroenterology

KADEFORS, R. & PETERSEN I (1970) Spectral analysis of myo-electrical signals from muscles of the pelvic floor during voluntary contraction and during reflex contractions connected with ejaculation Electromyography 10 45 67

KERREMANS R (1969) Morphological and physiological aspects of anal continence and defaecation Arscia uitgaven N V Brussel

LOCALIO S.A. FRANCIS K.C & ROSSANO P G (1967) Abdominosacral resection of sacrococcygeal chordoma. Ann Surg. 166 394 402

MACCARTY C S. WAUGH J M MAYO C W & COVENTRY M B (1952) The surgical treatment of presacral tumors a combined problem Proc Staff Meet Mayo Clin 27 73 84

MARKLAND C MERRILL, D CHOU S. & BRADLEY W (1972) Sacral nerve root stimulation a clinical test of detrusor innervation J Urol. 107 772 776

MCDONALD D F & MURPHY G P (1959) Quantitative studies of perception of thermal stimuli in the normal and neurogenic urinary bladder J appl. Physiol 14 204 206

MCELHANEY J H (1966) Dynamic response of bone and muscle tissue J appl. Physiol 21 1231 1236

NACHEMSON A. & ELFSTRÖM G (1970) Intravital dynamic pressure measurements in lumbar discs. Almqvist & Wiksell Stockholm.

NATHAN P W (1952) Thermal sensation in the bladder J Neurol Neurosurg. Psychiat 15 150 151

PEARLMAN A.W & FRIEDMAN M (1970) Radical radiation therapy of chordoma. Amer J Roentgenol 108 333 341

PETERSEN I & STENER, I (1970) An electromyographic study of the striated urethral sphincter the striated anal sphincter and the levator ani muscle during ejaculation. Electromyography 10 23 44

RATHKE F W & SCHLEGEL, K.F (1974) Wirbelsaule und Becken (Band III) In Orthopadisch chirurgischer Operationsatlas. Ed by Hackenbroch, M and Witt, A N Georg Thieme Verlag, Stuttgart

RAY B S. & NEILL, C L (1947) Abdominal visceral sensation in man Ann. Surg. 126 709 724

RETIEF P J M. (1950) Physiology of micturition and ejaculation. Sth afr med J 24 509 512

RUFF, S (1950) Brief acceleration less than one second In German Aviation Medicine World War II U S Government Printing Office Washington D C 1 584 597

SCHUSTER, M M , HENDRIX T R & MENDELOFF, A J (1963) The internal anal sphincter response Manometric studies on its normal physiology, neural pathways and alteration in bowel disorders J clin Invest 42, 196 207

SCHUSTER M M HOOKMAN P , HENDRIX, T R & MENDELOFF A J (1965) Simultaneous manometric recording of internal and external anal sphincteric reflexes Bull John Hopkins Hosp 116 no 2 79 88

SCHUSTER M M (1968) Motor action of the rectum and anal sphincters in continence and defecation In Handbook of Physiology sect 6 Alimentary canal Ed by C F Code Washington D C American Physiological Society

SCHUSTER, M M (1975) The riddle of the sphincters Gastroenterology 69 249 262

SENGER F L & ROTHFELD S H (1947) On sensation of the bladder – a preliminary report Urol Cut Rev 51 454 456

SHERRINGTON, C S (1892) Notes on the arrangement of some motor fibres in the lumbosacral plexus J Physiol , Lond 13 672 675

STECKLER, R M & MARTIN R G (1974) Sacrococcygeal chordoma Am Surg 40, 579 581

TALAAT M (1937) Afferent impulses in the nerves supplying the urinary bladder J Physiol 89 1 13

WILSON, P W (1972) A clinical study of the biomechanical behaviour of massive bone transplants used to reconstruct large bone defects Clin Orthop Rel Res 87 81 110

ÖRTENGREN R (1975) A filter bank analyzer with simultaneous read out for the evaluation of dynamic myoelectric signal power spectra Medical and Biological Engineering 13 561 569

RUFF, S (1950) Brief acceleration less than on
cline, World War II, U S Government Print
597.

SCHUSTER, M M, HENDRIX, T R & MENDELE
sphincter response Manometric studies on n
ways and alteration in bowel disorders J clin

SCHUSTER, M M, HOOKMAN, P, HENDRIX T R
Simultaneous manometric recording of interna
reflexes Bull John Hopkins Hosp 116 no 2 7

SCHUSTER, M M (1968) Motor action of the rectum
nence and defecation In Handbook of Physiolo
Ed by C F Code Washington D C American Ph

SCHUSTER M M (1975) The riddle of the sphincters
502

SENGE R, T T & ROTHBERGER, SH (1947) On sensatio
wall report Cond Clin Res 31 454 456

SHERRINGTON, C S (1892) Notes on the arrange ment o
lumbosacral plexus J Physiol Lond 13, 672 675

SHICKER, R M & MARTIN R G (1974) Sacro[illegible] ge
44, 570 [illegible]

TALAAT M (19[illegible]) [illegible] impulses in the nerves supply
J Physiol [illegible]

WILSON P M (1972) [illegible] the biomechanical
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[illegible] (1975) [illegible] filter bank analysis and normal an
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R FEITH

SIDE-EFFECTS OF ACRYLIC CEMENT IMPLANTED INTO BONE

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ACTA ORTHOPAEDICA SCANDINAVICA
Supplementum No 161

From the Laboratory for Experimental Orthopaedics Department of Orthopaedics (head Prof Dr Th J G van Rens) Catholic University, Nijmegen The Netherlands

SIDE-EFFECTS OF ACRYLIC CEMENT IMPLANTED INTO BONE

A HISTOLOGICAL, (MICRO)ANGIOGRAPHIC, FLUORESCENCE MICROSCOPIC AND AUTORADIOGRAPHIC STUDY IN THE RABBIT FEMUR

BY

R FEITH

MUNKSGAARD COPENHAGEN 1975

THIS STUDY HAS ALSO BEEN SUBMITTED AS A THESIS TO THE CATHOLIC UNIVERSITY OF NIJMEGEN

To Anneliès
and to the memory of
my first and finest teacher
my grandfather
Jonkheer J M de Jonge C E

Translated by Th van Winsen

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CONTENTS

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INTRODUCTION

The range of application of polymethylmethacrylate (PMMA) as acrylic bone cement in orthopaedic surgery is steadily increasing In particular, the use of acrylic cement has facilitated the solution of numerous problems in the fixation of artificial joints This has made it possible to expand the use of artificial joints and to give many patients with invalidating arthropathies a better life

According to Muller (1974b), some one million patients have so far been treated by total hip replacement in Europe and the USA, and Bloch (1974) estimates that about a thousand total hip arthroplasties are now being performed every day all over the world!

Since the first total hip replacements with acrylic cement fixation were performed in the early Sixties, continued research has focused in particular on improvements in the mechanical characteristics of metal and plastic prosthetic components The orthopaedic surgeon is confronted with an unceasing flow of new types of prostheses, but acrylic bone cement has shown no fundamental modifications or improvements since it was first used by Charnley (1960) This is perhaps explained by the fact that the use of similar products in dentistry had been preceded by a long period of research

Although acrylic cement has generally lived up to its expectations problems of fixation have not yet been fully solved Loosening of the prosthesis is being encountered in an increasing number of total hip replacements, often years after its implantation and after an initial clinical course which could only be described as favourable (Amstutz 1970, Wilson and Scales 1970, Wilson et al 1972, Patterson and Brown 1972 Salenius and Laurent 1973 van Rens 1973, Muller 1974a 1974b Deutman 1974, Dandy and Theodorou 1975) This late loosening, which totally invalidates a good result, is one of the greatest problems of total hip replacement today According to Muller (1974b) a 10 year follow up on patients treated by total hip replacement can be expected to show that some 20 per cent will need a secondary operation in view of late complications, loosening being the most common This applies to patients operated on in highly specialized clinics by experienced surgeons

It is not easy to diagnose loose prosthesis and it may be several years before the situation is clinically evident Arthrography (Salvati et al 1971) and Strontium ^{87m}Sr bone scanning (Feith et al 1975) have proved to be

valuable diagnostic aids The late complication rates reported even in larger series should not be taken for granted. It may well be that patients coming back with obscure pain and diminished mobility and function are really suffering from a loose prosthesis and in whom the diagnosis has been missed The proper diagnosis should have increased the total percentage of late loosening Moreover in cases of late infection (always associated with loosening of a prosthesis component) it is rarely possible to establish whether the aseptic loosening or bacterial infection was the primary development

Possible causes of late loosening of normally used total hip prostheses include necrosis and resorption of the bony implant bed, insufficient cementing excessive friction between the components of the prosthesis *infection shrinkage of acrylic cement and sensitization to detached metal* particles resulting in low grade infection All these processes take place at the interface between bone and acrylic cement Starting from the oper ation the bone at this site is exposed to successively mechanical lesions caused in preparing for the implantation and thermic as well as chemical toxic influences exerted by the cement Partly due to interruption of the bone vascularization and partly due to direct damage this results in the thin layer of necrosis of the bony implant bed described by Charnley (1970) and by Willert and Puls (1972) and Willert et al (1974b) As a result the initial direct contact between bone and cement is partly lost In the majority of cases adaptation of the implant by organization of the necrosis and regeneration of new bone is sufficient to produce what could be described as the recipient s tolerance to the foreign body In other cases however in which the fixation of the components by the acrylic cement is lost this necrosis might well be the principal cause of late loosening of the prosthesis and it might also be the factor predisposing to late infection

The reasons why this necrosis develops has so far remained obscure The purpose of this study is to investigate the three factors generally accepted as causative separately and in combination in experiments using the rabbit femur These factors, of which the first two should be regarded as local side effects produced by the acrylic cement are

1 the high maximal polymerization temperature of the acrylic ce ment setting in situ
2 the local cytotoxic effect of the monomer
3 interruption of the osseous vascularization by surgical mani pulations required to prepare for implantation

Part of this study was presented as preliminary report at the 7th *International Bi materials Symposium held in Clemson, USA (Feith and Slooff 1975)*

CHAPTER 1

ACRYLIC BONE CEMENT

1.1 *Introduction*

Polymethylmethacrylate (PMMA) was first used on a larger scale in orthopaedic surgery when the brothers Robert and Jean Judet introduced their Perspex or Plexiglas femoral head prosthesis in 1946. The initial results seemed promising (J. Judet et al. 1952) but in the longer run the acrylic prosthesis was found to be biologically and mechanically unsuitable for clinical use (Muller 1962, Anderson et al. 1964, Salvati and Wilson 1973). The Judet type metal prosthesis (La Chapelle) was likewise found to be unsatisfactory. The subsequently developed metal head neck prostheses (best known types: Austin Moore, Thompson, Eicher and Muller) were a marked improvement. However, not all biomechanical problems were yet solved. The fixation of these hemiarthroplasties remained the principal problem.

The interest in PMMA, but now as "bone cement", was revived when Charnley (1960) – advised in his choice of plastic by D. C. Smith – stabilized his first hemiarthroplasty of the hip with cold-curing PMMA. Shortly after, Charnley (1961) and McKee and Farrar (1966) each developed a total hip prosthesis which they anchored with acrylic cement. Since the early Seventies, this bone cement has become an indispensable aid in orthopaedic surgery. The method of fixation which fills the space between the joint replacement and previously prepared bone defects with malleable plastic setting in situ, was revolutionary. It was therefore not until several years later that the concept of relying on the strength of the cement to support the prosthesis rather than having it rest on the bone, was generally accepted. Acrylic cement heralded the era of total joint replacements.

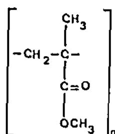
Excellent studies on PMMA have since been published in Dutch (Slooff 1970), English (1970) and German literature (Contzen et al. 1967, Oest et al. 1975*). To avoid repetition, the following sections will review only such aspects as are relevant to this study, and will discuss some recent developments.

* Published after completion of this manuscript.

1 2 *General characteristics*

1 2 1 Composition of the components

Polymethylmethacrylate is a plastic material composed of macromolecules These in turn are made up of smaller units called monomers which, linked by chemical double bonds as a result of polymerization form the links of the polymer chain The everrepeated unit in acrylic bone cement is the methyl ester of methacrylic acid (methylmethacrylate) Therefore the chemical name of the polymer is polymethylmethacrylate



The material is prepared for implantation by mixing polymer powder with liquid monomer, which consists mainly of methylmethacrylate The powder consists of tiny spherical particles of polymerized polymethylmethacrylate to which about 1 per cent benzoyl peroxide has been added (the initiator or catalyser)

The powder can in addition contain co polymers of methylmethacrylate with butyl methacrylate and styrene It is also possible to add some radiopaque substance such as barium sulphate or zirconium dioxide as well as antibiotics The latter are released in a locally effective dose (Wahlig et al 1972 Wahlig and Buchholz 1973 Koschmieder et al 1973 1975) The highest effective local concentration can be attained with gentamycin sulphate (*Refobacin® Garamycin® usual dosage 500 mg/40 mg polymer* powder) (Hessert and Ruckdeschel 1970 Buchholz and Gartmann 1972 Wahlig et al 1972 Ruckdeschel et al 1973 Marks et al 1975)

After release from the cement of initially high microbiological concentrations of the antibiotic during the first three days it is believed that a minimum inhibitory con centration of sufficient height can be maintained in the *immediate vicinity of the* implant up to 5 6 months after implantation (Wahlig et al 1972 Wahlig and Buchholz 1973) According to Buchholz (1973) the antibiotic is still demonstrable even after 24 months It is believed that addition of 100 mg streptomycin to the polymer powder ensures sufficiently high tuberculostatic concentrations in the tissue surrounding the implant (Knapmann 1974)

The liquid monomer is an inflammable volatile, highly lipophilic fluid which has been demonstrated to be cytotoxic (Hulliger 1962 Willert et al 1973c) A stabilizer or inhibitor (hydroquinone) has been added to it in order to prevent spontaneous polymerization as activator has been

added a tertiary amine (dimethylparatoluidine) which releases from the benzoyl peroxide the free radicals required to open the double carbon bond in the monomer No heat is required to initiate the reaction hence the term cold-curing

1 2 2 Handling and curing characteristics

The components form a system in which the relative quantities have been carefully determined by the manufacturer and it is ill advised for the surgeon to alter the proportions indicated The mixing of polymer powder and monomer liquid produces a soft paste which has the typical odour of the volatile monomer In order to ensure maximum escape of the cytotoxic monomer prior to implantation the substance is not introduced until after 1 5-4 minutes when it has become putty like and there is just sufficient working time left to mould it at the appropriate site in the bone whereupon the prosthesis is placed in position It is of importance to ensure that the cement mass is still sufficiently malleable to enter even the smallest interstices in the bone After waiting too long the cement laminates and becomes mechanically weaker (Lee et al 1973)

Kutzner et al (1974a) determined by biological means that, after mixing acrylic cement (Palacos) at normal speed for 2.5 minutes, a total of 1 11 per cent monomer is released by evaporation up to 0 minutes after joining the components. Lee et al (1973 1975) found that monomer evaporation is promoted by thorough mixing especially important was their finding that the amount of monomer released is directly proportional to the rate of stirring. Up to 14 per cent of the monomer could evaporate at a stirring rate of 60 beats per minute The duration of mixing also played a role but was less important When mixing was discontinued, monomer evaporation was slight this was confirmed by Roggatz (1974) and Debrunner and Wettstein (1975b) When mixing was resumed for 1 minute, ten times as much monomer was found to evaporate as when the cement was left alone A similar effect was obtained by manual kneading for 1 minute (Lee et al 1973 1975) It is to be pointed out that manual kneading accelerates the setting process and slightly increases the maximal temperature peak due to an increase in ambient temperature (Haas et al 1975)

Willert et al. (1973c) demonstrated in an experimental study that the cytotoxic effect of escaping monomer can be substantially reduced by having polymerization take place outside the body as long as possible. In a preliminary report, Debrunner and Wettstein (1975b) maintained that the principal monomer release occurs during the increase in temperature at polymerization In their arrangement, no release was measurable any longer 2 3 minutes after setting.

The exothermic polymerization process needs some time to get properly started With increasing heat release the phase in which the material is plastic ends and setting commences (fig 1) When the cement is setting the maximum curing temperature is reached at about the same time this can locally be as high as about 100° C The setting process still continues

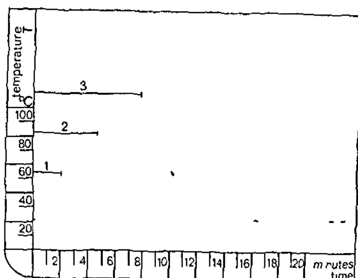


Fig 1 General shape of a temperature time curve of acrylic cement to elucidate the concepts of terms mixing time (1) working time (2) and setting time (3) these are represented schematically The duration indicated for (1) (2) and (3) *is arbitrary*

and it is only after several hours that the material attains its definitive degree of hardness (Haas et al 1975)

The working time of the various commercial bone cements varies considerably (Willert et al 1973c, de Wijn et al 1975, Debrunner and Wettstein 1975a) Other factors also play a role For example, when the powder liquid ratio diminishes (thereby increasing the amount of monomer), the setting time increases and the polymerization temperature attains a higher maximum (Meyer et al 1973)

Apart from the constituents the speed of the reaction is also dependent on the volume of the cement mixture and on the ambient temperature The larger the cement mass the longer the setting time Not only the room temperature but also that of mixingbowl, spatula operation lamp and the body temperatures of surgeon and patient must be taken into consideration (Meyer et al 1973) A higher ambient temperature shortens the working time and setting time, and vice versa *By increasing* the ambient temperature by 10° C the polymerization process is accelerated by factor 1 5-2 and the working time is therefore halved (Debrunner and Wettstein 1975a) The maximum polymerization temperature attained also increases as the ambient temperature rises (Meyer et al 1973)

1 2 3 Polymerization heat

It has been reported that about 130 calories are released in the reaction per gramme of polymerizing monomer (*Meyer et al* 1973, Labitzke and

Paulus 1974). This implies that the total amount of heat produced increases when a larger amount of acrylic cement is used, while the maximum polymerization temperature increases as well. As the polymerization process advances, the reaction accelerates and more calories are released per unit of time (Debrunner 1974). The maximally attainable polymerization temperature is variously reported in literature as from 40 to 120 °C (Wiltse et al. 1957, Slooff 1970, Debrunner 1974). The wide range of variation in laboratory results is explained by Slooff (1970) and by Hupfauer and Ulatowski (1971) on the basis of *insufficient standardization* of

1. the measuring devices used,
2. the site of measurement in the cement,
3. the amount and consistency of the cement,
4. the monomer : polymer mixing ratio,
5. the surrounding material,
6. possible supply and release of heat,
7. measuring in vitro or in vivo.

Of course the maximum temperature of the cement surface measured in vivo is conclusive of any possible thermic tissue damage. In this context the German-speaking authors attach great value to the critical limit of 56 °C indicated by Lehmann (1959), at which body protein is alleged to coagulate, or to a limit of 70–72 °C, which Labitzke and Paulus (1974) hold to be the temperature at which bone collagen coagulates. These authors maintain that *thermic necrosis need not be feared as long as one* remains below this limit.

In in vivo measurements in the bone-cement interface in dogs, Homsy et al. (1972a) found temperatures of 70–90 °C. Meyer et al. (1973) reported having found a maximum temperature of 70 °C in the bone/acrylic interface during total hip arthroplasty in 10 different patients. In 10 patients treated by total hip arthroplasty, Biehl et al. (1974) measured in the trochanteric region a mean temperature of 46.6 °C (range 42.6–51 °C), and Labitzke and Paulus (1974) reported a mean temperature of 45.2 °C (± 3.4 °C) in 5 such patients. The last-mentioned authors found a mean maximum temperature of 50.4 °C (± 7 °C) at the interface of the prosthesis cup. Biehl et al. (1974) measured a mean temperature of 43.6 °C (range 43–45.9 °C) at the end of the femoral component of the prosthesis. Near the acrylic cement and according to Debrunner (1974) from only 3 mm from the cement surface on, the maximum measurable temperature is much less high, not exceeding *two fifths of the temperature* of the cement surface. He thought it likely that in living tissue with an intact blood circulation the increase in temperature would be even less

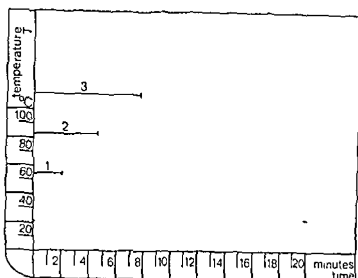


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1 2 3 Polymerization heat

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2 Apart from air bubbles, acrylic cement setting in situ also loses strength due to admixture of blood and bone marrow The manner of application of the cement also influences its homogeneity Apart from other advantages of using a cement syringe, the risk of gross irregularities in the cement mass and a difference in consistency b tween the first and the last cement plug is much less after introduction by means of a syringe than after digital introduction (Slooff 1969 de Wijn et al 1974a)

3 Addition of a radiopaque substance and/or an antibiotic was reported not to interfere with the mechanical strength of the cement (Hessert 1971 Marks et al 1975) This however, was refuted by Grunert and Ritter (1974) de Wijn et al (1975b) and Haas et al (1975) who demonstrated that these additions cause mechanical weakening of the cement due to loss of homogeneity and increased water absorption

4 Finally there are indications that acrylic cement ages in situ Water absorption alters the mechanical quality (Bloch and Hastings 1972 Wagner and Bourgeois 1974)

Oest and Muller (1973) reported that test specimens of acrylic cement polymerized under pressure (dimensions 60 x 6 x 4 mm) and when kept in Ringer solution at 20 C were found to be saturated with water after about 75 days Their weight had increased by 1 6 per cent, and they had therefore lost 20 per cent of their hardness An increase in temperature to 40 C resulted in another 20 per cent loss of hardness (Oest and Muller 1973) Jaffe et al (1974) however were unable to demonstrate any significant deterioration of static properties or compression fatigue behaviour in specimens of acrylic cement kept in bovine serum at 37 C for up to two years

As a result of the above mentioned factors the ultimate compressive and tensile strengths of Simplex P set in vivo are according to Homsy (1973) and Lautenschlager et al (1974) on average only 20 35 per cent of those of polymer obtained under factory conditions Acrylic cement obtained at re operation was submitted to various strength determinations and found to be 50 per cent weaker than homogeneous test specimens (Oest and Muller 1973 de Wijn et al 1974a 1975b)

de Wijn et al (1974a 1975b) reported that in particular the greater porosity of PMMA setting in situ has an unfavourable effect on its mechanical properties It is difficult to answer the question whether weakening of the acrylic due to the above mentioned factors is of essential significance for the success or failure of a joint replacement operation. No exact figures are available on the minimum requirements which the mechanical properties of acrylic cement should meet (de Wijn et al 1975b)

Acrylic cement is not a glue nor does it form any bond with living tissue at the molecular level It is exclusively a filler which mechanically

than in the model set up This hypothesis was confirmed by Biehl et al (1974) in comparative measurements at the interface between bone and cement during implantation of total hip and knee replacements The knee prostheses were introduced under tourniquet ischaemia, and in these cases unmistakably higher temperatures were measured (on average 9 4° C higher)

Irrigation of bone surface and prosthesis has no significant effect on the maximum temperature (Ohnsorge and Goebbel 1970, Meyer et al 1973) It was found possible to reduce the maximum polymerization temperature by using prostheses cooled to 0° C (Ohnsorge and Goebbel 1970), by adding metal powder to the cement mixture (Homsy et al 1972), and by addition of co polymers with longer chains (de Wijn 1974) The lastmentioned principle was used in the manufacture of the commercial acrylic cement Sulfix®, discussed in section 3 2 It is doubtful, however whether these methods can sufficiently reduce the temperature to prevent thermic tissue damage Moreover, the use of cooled prostheses has a number of disadvantages For example, the marked auto accelerating effect of the exothermic reaction, which gives this cement such attractive features for use in fixation, is inhibited (de Wijn 1974) Secondly, insufficient polymerization has an unfavourable effect on the mechanical properties of acrylic bone cement, and increases the percentage of monomer left in the cement (Puhl and Schulitz 1971, Willert et al 1973c)

1 2 4 Mechanical properties

Studies with the scanning electron microscope (SEM) have shown that the structure of acrylic cement consists of an aggregate of previously polymerized polymer pearls, retained by cohesion to recently polymerized monomer Polymerized PMMA, therefore is a composite material in which no chemical bond has been established between polymer pellets and the monomer methylmethacrylate

Many investigators have submitted the material to mechanical tests demonstrating that it offers great resistance to compressive stress but less resistance to tensile and shear stresses (Wiltse et al 1957 Charnley 1970 Lautenschlager et al 1974 de Wijn et al 1975b Haas et al 1975)

Several factors exert a negative influence on the mechanical properties

1 Acrylic cement set in situ shows a certain degree of porosity due to inclusion of air bubbles during mixing and evaporation of monomer during the marked increase in temperature The pores form a closed system and therefore do not communicate with each other Porosity and mechanical hardness are inversely proportional (Debrunner 1975, de Wijn et al 1975b)

The question of the general pharmacological effect of monomer on the human organism has received renewed attention since 1970 The reason was that cardiovascular complications were an unpleasant surprise in a procedure (total hip arthroplasty) which was rapidly gaining acceptance Apart from reports on transient hypotension usually observed immediately after introduction of acrylic c ment and prosthesis into the femoral shaft the Anglo-American literature in particular presented from 1970 onwards a large number of case reports describing peroperative sometimes irreversible cardiac arrest during hemiarthroplasty and total arthroplasty of the hip and total knee replacement. Series of such case reports recently compiled by Milne (1973) Dandy (1974) and Herndon et al (1974) can probably be supplemented with a by no means negligible number of un published cases Despite Charnley s denial (1970) and its corroboration by the anaesthetists of the Wrightington Hospital (Brittain and Ryan 1972) some authors maintained that these cardiovascular complications were to be largely ascribed to the cytotoxic lipophilic (residual) monomer Later research has differentiated these views

Once PMMA is set 2 5 per cent residual monomer remains in the cement and 1 2 per cent is gradually diffused to enter the tissues in minute amounts (Smith and Baines 1956 Kutzner et al 1974a Haas et al 1975) According to Hullinger (1962) the initiator activator and inhibitor are not cytotoxic in the small quantities normally used

A discussion of the local cellular and acute pharmacological cytotoxicity chiefly refers to the non polymerizing monomer which is released in the organism during the reactive process The possibly unfavourable effect of the so-called residual monomer (2 5 per cent) is negligible The only thing really known about the local deleterious effect of non polymerizing monomer is that methylmethacrylate is cytotoxic The extent to which it may possibly contribute to tissue necrosis is unknown No research in this direction has so far been undertaken

According to Kutzner et al (1974a) methylmethacrylate is pharmacologically active in 1 11 per cent of the monomer added to the mixture (page 15) Monomer can be demonstrated in venous blood after intra femoral application of acrylic cement in dogs (Homsy et al 1972a Mc Laughlin et al 1973) and human subjects (Bloch et al 1970 Kim and Ritter 1972 Philips et al 1973 Pahuja et al 1974) The maximum con centration is reached during the rapid increase in polymerization temper ature but shortly afterwards it is no longer demonstrable in venous blood samples Intravenously administered to test animals the monomer was found to have three pharmacological effects

a. It increased the rate of respiration and in increased doses led

stabilizes the cemented prosthesis Compressive, torsional and tensile forces are divided over a large bone surface area by the cement (Charnley 1970) Anchoring is further enhanced by intimate *interlocking of the* cement with surface irregularities

Stabilization of a prosthesis with acrylic cement partly depends on the number and the efficiency of interlockings of projections of the cement surface with *surface irregularities of the surrounding bone tissue* (Homsy 1973) The layer of fibrous connective tissue which forms at the interface (cf pages 25 to 30) allows minimal movements between bone and cement surface Charnley (1965, 1970) does not regard these as a disadvantage *in fact* he rather regards this fibrous interposition as a shock absorber which permits of elastic deformation between bone and cement – substances of different stiffness (the stiffness of PMMA is less than that of cortical bone but exceeds that of cancellous bone)

Mechanical theories become substantially more complex when the mechanical strength of the in vivo „bond' between bone and acrylic cement is to be calculated, with the prosthesis in situ or otherwise Numerous variables are then to be taken into account e g body weight, jolting stress, vascularization, mineralization and architecture of the bone as well as position, shape and mechanical properties of the prosthesis (Charnley 1965, 1970, Slooff 1970, Wilson and Scales 1970, Kolbel and Boenick 1972, Oest 1973 Kolbel et al 1973, Ritter et al 1973 Walker 1973, Jager et al 1974, Chen et al 1974) This general introduction does not lend itself to a detailed discussion of this complex subject

1 2 5 *Volumetric changes*

Theoretically predictable shrinkage (Contzen et al 1967, Haas et al 1975) of the product of polymerization was not corroborated by Charnley (1970) He measured an increase in volume by 3-5 per cent In subsequent studies Hupfauer (1973), Ohnsorge and Grotz (1974), Debrunner (1975) de Wijn et al (1975c) and Haas et al (1975) concluded that after a slight initial increase in volume due to thermic expansion and foaming of the mixture, cooling of the mass to ambient temperature after curing causes a decrease in volume The percentages of decrease in volume reported by the above-mentioned authors vary from 1-4 volume per cent depending on the technique used In other words the cement shrinks during the period of rapid polymerization As the cement mass absorbs water some of this volume loss can be regained in the long run (Oest and Muller 1973 Ohnsorge and Grotz 1974 de Wijn et al 1975c Haas et al 1975)

Whether this slight decrease in volume during the final rapid phase of polymerization might contribute to loosening of prostheses is unknown In any case, this inevitable shrinkage cannot be expected to enhance fixation

1 2 6 *General toxicity of the monomer*

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a It increased the rate of respiration and in increased doses led

to respiratory arrest by a direct inhibitory effect on the respiratory centre (McLaughlin et al 1973, Kutzner et al 1974b),

b It caused hypotension probably as a result of decreased peripheral resistance in spite of an increase in cardiac output which as such might be caused by an increasing heart rate (Homsy et al 1972a, Peebles et al 1972, Holland et al 1973, McMaster et al 1974, Ellis and Mulvein 1974, Berman et al 1974),

c In large doses, it caused degeneration of pulmonary, hepatic and renal parenchyma (Contzen et al 1967, Homsy et al 1972a, McLaughlin et al 1973, Holland et al 1973)

The effects on respiration and blood pressure were both dependent on the monomer dose given

The hypotensive effect, moreover, can apparently be potentiated by a deficiency in circulating volume In addition Berman et al (1974) demonstrated in hypovolaemic dogs a decrease in cardiac output which in their view was caused by venodilatation (monomer effect), resulting in venous pooling and diminished venous return It may also be mentioned that no ECG changes were found in test animals

In an analysis of possible local and systemic side effects of acrylic cement in human individuals, Convery et al (1975) were unable to demonstrate any untoward effects of PMMA on pulmonary hepatic and renal function in patients after total hip replacement The majority showed mild transient hypotension, especially during application of acrylic cement and insertion of the endoprosthesis into the femoral shaft In the 10 patients whose cardiovascular function was recorded during the operation the most constant change was a decrease in mixed venous oxygen saturation The most logical explanation in their view was a decreased cardiac output probably caused primarily by peripheral venous pooling The authors (Convery et al 1975) apparently advanced their theory on the basis of Fick's principle this however applies only in a steady state and it is questionable whether a steady state is really maintained during introduction of acrylic cement and a prosthesis into the femoral shaft It is difficult to be certain what possible effect the monomer on its own can have So many other factors can influence the circulation

Modig et al (1973b) stated in a preliminary report that fat particles were found in blood samples from the pulmonary artery immediately after insertion of the femoral prosthesis in three out of four patients undergoing total hip arthroplasty With the aid of a Doppler flowmeter placed over the femoral vein Herndon et al (1974) demonstrated fat embolism in patients during total hip replacement The largest number of „chirps" were heard during insertion of the femoral prosthesis Only an occasional chirp was heard during introduction of the cup preparation

of the proximal femur and introduction of the cement into this The fat emboli thus demonstrated were also identified in blood samples obtained from the femoral vein during the operation In a painstaking postoperative investigation they found no indications of systemic fat embolism The number of fat emboli could be unmistakably reduced by venting the medullary cavity with a catheter attached to suction during introduction of the prosthesis or by making burr holes in the lateral femoral cortex

Although Herndon et al (1974) did not explicitly state this these fat emboli can be assumed to have originated from the medullary cavity (chapter 2 page 45) in view of findings reported by Danckwardt Lilliestrom et al (1970a 1970b) and Kallos et al (1974) The emboli enter the blood stream as a result of increased intramedullary pressure during the operation particularly while the femoral prosthesis is being forced into the cement mass Pressure determinations in patients during total hip replacement have confirmed the relevant results of animal experiments (e g Philips et al 1973 Tronzo et al 1974) It is quite conceivable that a causal relationship exists between these fat emboli and the above-mentioned acute peroperative cardiac arrests for postmortems have repeatedly revealed massive pulmonary fat and bone marrow embolisms in these casualties (Milne 1973 Dandy 1974 Herndon et al 1974)

In these cases however external heart massage had been applied and in view of observations made by Jackson and Greendyke (1965) and Zichner (1970) the above mentioned findings should be viewed with some reticence for these authors found fat and bone marrow emboli in the lungs at postmortems on 80 per cent of patients who had died after external heart massage without preceding trauma Regarding the cardiovascular complications in these usually elderly patients some relation to type and concentration of drugs administered during anaesthesia also seems likely even though it is refuted by some authors (Brittain and Ryan 1972) Others (e g Fearn et al 1972) have confirmed it However comparison of anaesthetic techniques is almost impossible

To summarize the above it can be stated that it has not so far been demonstrated with certainty that the monomer in the amount released during such procedures as total hip replacement has any general pharmacological side effects on human patients Cardiovascular complications during hip replacement are more readily explained on the basis of systemic fat embolism A possible hypothesis is that of a combined effect or even an interaction between monomer and fat embolism in the sense that the monomer is partly responsible for the development of fat emboli And the high polymerization temperature of the cement may also be of significance in this respect.

The only study referring to a combined effect has been one by Schlag et al (1973) who studied various cardiovascular functions in rabbits and dogs during intrafemoral

application of acrylic cement They advanced the hypothesis that circulatory decompensation results from an increased pulmonary vascular resistance to which three factors contribute Fat and bone marrow emboli are held responsible for mechanical obstruction of the pulmonary microcirculation believed to be further aggravated by the release (potentiated by the bone marrow emboli) of a thromboplastin like substance giving rise to platelet aggregates The last suggestion was also made by Modig et al (1973a) The third factor directly attributed to the monomer is described to produce oedema of the alveolocapillary membrane in the lungs which via reduction of the pulmonary microcirculation will contribute to increased pulmonary vascular resistance which could end in acute cor pulmonale

The possibility of interaction between monomer and fat embolism on the other hand was suggested in studies by Dustmann et al (1972) and Koch et al (1972) They demonstrated histological features of extensive pulmonary embolism in six out of eight cats submitted to subtrochanteric femoral osteotomy reaming of the medullary cavity and intramedullary implantation of bone cement When the cement application was preceded by pressure relieving suction drainage mild fat embolism was demonstrable in only five out of ten animals Fat embolism was likewise only slight when a different substance (Plasteline) was introduced into the medullary cavity without suction drainage this fat embolism became more marked when liquid monomer was introduced into the femoral shaft in addition When the procedure was repeated this time applying acrylic cement after intravenous injection of 5 ml of the fat emulsifier choline phospholipid (Lipostabil) only two of the ten animals showed slight pulmonary fat embolism Of the ten animals in which the Lipostabil injection was combined with suction drainage of the medullary cavity none developed pulmonary fat embolism The authors concluded from these results that the monomer is of essential significance in the causation of fat embolism

In conclusion, it can be stated that even though no definite results have been reached, it can safely be admitted that application of acrylic cement, particularly in the femoral shaft, is known to cause a slight decrease in blood pressure and occasionally severe hypotension It seems therefore advisable to observe a number of rules The surgeon should ensure optimal mixing as long as possible outside the organism and provide adequate ventilation of the femoral shaft the endoprosthesis should moreover be eased into its proper position Points of importance to the anaesthetist are to ensure adequate filling of the circulating volume before introduction of acrylic cement, and prevention of even slight hypoxia The possible contribution of the cytotoxic monomer to local tissue necrosis remains unknown

1 2 7 Allergy

So far there have been no indications of significant allergic complications caused by acrylic cement (and particularly by the monomer methyl methacrylate) in orthopaedic applications Sensitization to the monomer as reported in dermatological and dental literature (Slooff 1970 Charnley 1970), however has been described in orthopaedic surgeons with contact

dermatitis (Pegum and Medhurst 1971 Blair Fries et al 1974) and in patients after total hip replacement with the aid of bone cement (Blair Fries et al 1974) The monomer seems to penetrate surgical gloves readily

Until the contrary is proved the possibility that allergic reactions with serious consequences for the patient can be provoked by the cement components or additives must be taken into account (Bloch and Hastings 1972 Muller 1974b)

1 2 8 Carcinogenic effect

Partly in view of reports on sarcomatous degeneration after application of PMMA in test animals (Contzen et al 1967 Slooff 1970 Charnley 1970) the Food and Drugs Administration has long delayed acceptance of acrylic cement in the USA Finally in 1971 only one product (Simplex P) was accepted There has been one case report on malignant degeneration following surgical application of PMMA

Some 18 years after application of Lucite for extrapleural plombage of a tuberculous pulmonary process an extraskeletal chondrosarcoma was found in the supraclavicular fossa which proved to be directly related to the fibrous capsule enveloping the Lucite (Thompson and Entin 1969)

So far as could be established no malignant degeneration has ever been ascribed to any orthopaedic application of PMMA. However after exposure of the human organism to recognized carcinogens it may be 20 35 years before a malignancy becomes manifest (Ott 1970 Lavorgna et al 1972) In view of the long latent period no definite conclusion can as yet be reached about the carcinogenic effect of acrylic cement on the human organism Discriminate use and prolonged follow ups particularly on younger patients are therefore imperative

1 3 *Histopathological reactions*

1 3 1 Introduction

In descriptions given in the past of the effect of PMMA on living tissue distinction must be made between tissue changes occurring in reaction to

a polymerized PMMA

b PMMA setting in situ

All authors quoted by Contzen et al (1967) Slooff (1970) and Charnley (1970) regard polymerized acrylic cement as a biocompatible material The principal reaction mentioned is the development of a connective tissue membrane at the interface between PMMA and living tissue

When this material is exposed to stress, signs of chronic inflammation are seen in the connective tissue layer, with reactive necrosis and increased remodelling in adjacent bone tissue These reactions can increase due to disintegration of the PMMA and, together with mechanical imperfections, this ultimately led to rejection of the Judet type of Plexiglas prosthesis as mechanically and biologically unsuitable

The situation of PMMA setting in situ – the acrylic bone cement – is a different one It is in fact highly dubious whether this could be described as a biocompatible substance The possible untoward local side effects of the bone cement, most important among which is the high polymerization temperature and the cytotoxicity of the non polymerizing monomer, become manifest in contact with the living organism The histopathological reactions which acrylic cement provokes in living human tissue can be divided into reactions in soft tissues and those in bone

1 3 2 Reactions in the soft tissues

After total hip arthroplasty, the movable parts of the artificial joints come to be surrounded by a new connective tissue capsule which replaces the capsule which is (usually) excised during the operation The histopathology of this new capsule, removed in revision operations or post mortems has been described by Cotta and Schulitz (1970) Semlitsch et al (1971), Willert (1973a), Willert and Semlitsch (1973b 1974a) Beneke et al (1973) Charosky et al (1973), Masshoff and Neuhaus-Vogel (1974), Evans et al (1974) and Brinkmann and Heilmann (1974)

Although the structure of the new capsule shows some resemblance to that of a normal joint capsule, yet an identical tissue structure is never attained The tissue structure shows changes and is much coarser because regenerative processes in the new connective tissue are accompanied by a tissue reaction to the presence of foreign bodies These foreign bodies are wear products of metal and plastic prosthesis components and bone cement particles from the implant bed

According to Willert and Semlitsch (1973b 1974a) acrylic cement particles are a major factor in the development of and the reactions in the new capsule They are held to contribute more to these than the wear products of the prosthesis components In the new capsule these foreign bodies produce a typical partly granulomatous foreign body reaction which varies with the degree of wear and other factors such as infection instability of the prosthesis and excessive amounts of acrylic cement The chronic foreign body reaction maintained by constant addition of newly formed wear particles leads to progressive thickening and cicatrization of the new capsule and over a long period of time this can produce

some loss of mobility in the artificial joint (Willert and Semlitsch 1973b 1974a)

The granulation tissue tends to become necrotic and necrotic material can be recovered in the form of cheese like debris from large pouches which have formed in the new capsule The wear particles are eliminated in minute amounts via the perivascular lymph interstices (Willert 1973a Willert and Semlitsch 1973b 1974a Brinkmann and Heilmann 1974) If this elimination is insufficient or if the supply is too large then this *may lead in the long run* to resorption of bone required for fixation of the cement with consequent loosening of the prosthesis components (Willert and Semlitsch 1974a)

Evans et al (1974) maintain that hypersensitivity to metal wear particles can lead to several reactions which via obliteration of supplying blood vessels give rise to necrosis of the bony implant bed and ultimately cause loosening of the prosthesis

The development of this capsule should be carefully watched because *it may give rise to pain functional impairment loosening* of the prosthesis and even possible sarcomatous degeneration (Willert and Semlitsch 1973b 1974a Charosky et al 1973) Although careful studies by the authors mentioned on page 26 have fortunately failed to demonstrate malignant degeneration following the use of acrylic cement in allo-arthroplasties Willert and Semlitsch (1973b) and Charosky et al (1973) never theless stress the potential risks entailed by chronic progressive cicatrization on the basis of a foreign body reaction in this context

1 3 3 Reactions in bone

Charnley (1970) described the histopathological changes of bone in contact with acrylic cement with reference to postmortem findings obtained in 23 patients who had shown an uneventful clinical course after implantation of an artificial joint which had remained stably fixed in the bone for many years (longest period reported 7 years) He observed *that* a thin layer of bone tissue (0 5 mm thick) in direct contact with the acrylic cement had become necrotic At the interface between bone and acrylic *cement a connective tissue* membrane had formed which contained giant cells but showed none of the typical signs of chronic inflammation From this connective tissue membrane a fibrocartilaginous tissue had developed by metaplasia induced by mechanical pressure In this tissue there were sometimes ossified areas in contact with underlying bone tissue Dead bone had in part been replaced by new *osteons which at* some sites lay against the cement However Charnley (1970) considered above all the fibrocartilaginous layer to be essential for the transmission of forces from cemented *prosthesis to bony implant bed*

On the basis of these observations and biomechanical theories (Charnley 1965) and supported by his good long term clinical and radiological results, Charnley (1970) described acrylic cement as a safe material which – although not yet ideal – meets all mechanical and biological requirements

Willert and Puls (1972) studied the histological reaction of bone to acrylic cement (Palacos) in 23 cases of total hip arthroplasty or hemi arthroplasty of the hip The material was obtained at postmortem the operations having been performed 7 days to 5 years before this examination

In all patients whose operation dated back more than 10 weeks, the implant had borne weight and the clinical result had been satisfactory In alle cases fixation of cement to bone was macroscopically firm, and no mobility between cement and bone tissue was demonstrable Intimate interlocking of the cement in the interdigitations of the cancellous trabeculae was found in the metaphysis Along the compact bone of the diaphysis and along the acetabular floor the cement did exactly follow the bone surface, but at these sites the bone architecture happens to be less suitable for fixation as firm as that is possible in cancellous bone In these areas the cement consequently showed a much smoother surface Necrosis was found in a thin layer of bone (up to 3 mm) surrounding the cement and large necrotic foci were found in the cancellous bone of the greater trochanter and in the medullary cavity of the femoral diaphysis distal to the point of the stem of the prosthesis Willert and Puls (1972) distinguished three phases in the tissue reactions to the implanted bone cement

a the initial phase, lasting up to 2 3 weeks after implantation
b the phase of reparation extending from 3 weeks to a year or longer,
c the phase of stabilization, which was completed after a maximum of two years

These three phases were best described in terms of microscopic features

In the initial phase fat cells and haemopoietic cells in the bone marrow degenerated There was lipophagia by polynuclear phagocytes which closely resembled foreign body cells The cancellous bone showed necrosis of cancellous trabeculae at sites of contact with the cement The extent of necrosis in the diaphyseal compact bone showed marked interindividual changes ranging from an area of 0 5 0 8 mm to one third of the inner surface of the cortex¹

The phase of reparation was characterized by organization of the bone marrow necrosis to fibrosis in which avital bone marrow elements were still demonstrable after as long as one year The boundary with the vital bone marrow was demarcated by a hyperaemic marginal zone Beginning in areas where the bone marrow had been revitalized remodelling processes were taking place in the necrotic bone Osteogenesis took place by metaplasia of connective tissue in which woven bone was deposited

or by deposition of new bone lamellae on old *necrotic cancellous* trabeculae In the diaphyseal compact bone mostly lamellated bone was deposited on the interior wall of the haversian canals. Bone trabeculae *anchored* in the cement could disappear entirely due to osteoclastic bone destruction with formation of lacunae especially in cortical bone The bone remodelling was not *confined* to the primarily necrotic areas. It was observed also in cancellous or compact bone areas not directly adjacent *to the implant, with predominance* of bone destruction. This produced rarefaction in the cancellous bone and porosity of compact bone The features of characteristic *osteoclastic osteoporosis could* be further enhanced by pre existent bone atrophy as seen in elderly patients The phase of reparation was found to be completed about ? *years after the* operation All necrotic tissue had been replaced by vital bone marrow nd bone and the bone cement was found surrounded everywhere by a thin layer of vital bone tissue

In the *phase of stabili ation* a collagenous connective tissue membrane of 0 1 1.5 mm *thickness was found as remnant of the above described bone marrow* fibrosis this membrane contained lymphocytes, plasma cells and polynuclear foreign body *giant cells The bone marrow otherwise* had a normal structure In the bone this phase was characterized by further remodelling with as conspicuous feature reorien tation in the course of the bone trabeculae While initially these had been arranged perpendicular to the bone cement, they were chiefly found to run more or less parallel to the cement surface in the phase of stabilization Total bony enclosure of the acrylic was not observed anywhere in the material examined By far the largest part of the interface consi ted of bone marrow which showed a smooth or latticed meshwork structure This bone marrow was separated from the cement by a connective tissue membrane in which in the phase of stabilization also haemorrhagic areas with fibrin deposits were seen.

In the initial phase the anchoring of cement in bone was most secure even though the interlocking bone trabeculae were usually avital Due to remodelling and reorien tation of the bone trabeculae interlocking of these trabeculae in the cement was much less in evidence in the phase of stabilization For the most part, the bone was not in d rect contact with cement but separated *from it by a thin zone of flat polynuclear* cells. These cells were probably to be regarded as the equivalent of the giant cells in the cement/bone marrow interface Wherever there was more space between bone and cement in the phase of stabilization smooth or latticed meshwork marrow was found separated from the cement by a connective tissue membrane.

The intensity of the changes described varied from case to case and therefore the interval required for revitalization of necrosis and the healing process also varied *The impression was gained moreover* that after early mobilization and weight bearing the processes of degeneration and regeneration of bone were better balanced and led to less extensive osteoporosis

The above described *findings* roughly correspond with those of Charn ley but they have been differently interpreted by Willert and Puls (1972) and Willert et al (1974b) They maintained that the implant of prosthesis with cement owes its stability to anchoring in bone In their view connec tive tissue membrane regenerated bone marrow and soft tissues grown into the cement may mechanically function as a buffer which absorbs excessive forces impinging on the implant They believe that the haemorrhages and exudates found in the connective tissue *membrane* corroborate this In their opinion the bone cannot be expected to interlock as intimately with

the cement during revitalization of the necrotic foci as at the time of insertion of the prosthesis According to Willert and Puls (1972), therefore, the anchoring in bone is never afterwards so firm as at the time when the cement is setting immediately after implantation!

Despite a favourable initial clinical course following a technically perfect operation, minimal movements between bone and implant can eventually occur due to diminution of the firmness of bony anchoring, as described by Charnley (1970), Willert and Puls (1972) and Willert et al (1974b) Should the demands made upon the implant exceed the strength of the cement/bone anchoring (and this is often unpredictable), instability of the implant inevitably results A series of microfractures in the interface upon continued stress can lead to loosening and even fracture of the cement (Homsy 1973 Willert et al 1974b) The tissue changes in the implant bed might very well lead to late loosening of the prosthesis It is therefore of importance to make an attempt at answering the ever-repeated question about the possible cause of this necrosis The three possibilities suggested are interference with the bone vascularization at operation, the high maximum polymerization temperature of the cement, and the cytotoxicity of the monomer

1 4 *Summary*

1 Acrylic bone cement as applied in joint replacing operations has generally fulfilled expectations
2 Polymerization entails the development of a high temperature and the release of non polymerizing cytotoxic monomer At a local level these side effects might contribute to necrosis involving a thin layer of the bony implant bed We do not know whether this necrosis is caused by the untoward side effects of cement setting in the living organism or whether a vascular factor is (also) responsible
3 The general pharmacological toxicity of the monomer methylmetha crylate, in the amounts commonly used in acrylic cement, is not alarming
4 Sensitization and carcinogenic effects of acrylic cement used for orthopaedic purposes have so far been unknown, but cannot be excluded with certainty in the long run
5 Several factors exert a negative influence on the mechanical qualities of PMMA Shrinkage of acrylic cement could well be an unfavour able factor of some importance
6 Cement particles can contribute to an unmistakable extent to the reactive development of a greatly thickened new joint capsule

CHAPTER 2

THE VASCULARIZATION OF DIAPHYSEAL CORTICAL BONE AND THE REACTIONS TO DISTURBED MEDULLARY CIRCULATION

2.1 *Introduction*

The direct relationship between vascularization and osteogenesis has been recognized for centuries but it is only in the past 25 years that attention and studies have focused on the anatomy of the osseous circulation on a microscopic level (Trueta 1968, Brookes 1971).

On the one hand this can be explained by the development of more advanced equipment to process bone and by the fact that perfected perfusion techniques have made it possible also to visualize microscopically small vessels. On the other hand the more aggressive attitude adopted in the past few decades by orthopaedic surgery in dealing with congenital and acquired anomalies of the musculo-skeletal system may also have given impetus to the renewed interest.

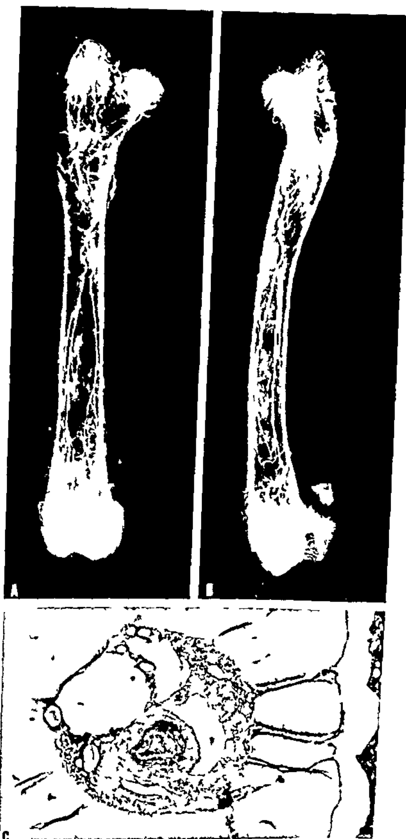
Our knowledge of the cortical circulation of diaphyseal bone in mammals which for decades was based on the works of Langer (1876), Lexer et al. (1904) and Johnson (1927) has been expanded in the years after World War II mainly by the results of animal experiments. It has been established that man and (test) animal, regardless of species, show the same basic patterns (Tilling 1958, Rhinelander 1962, 1972, Koekenberg 1963, Trueta 1968, Brookes 1971).

The arterial vascularization of a long bone has three sources: the nutrient artery, the metaphyseal arteries (in combination with the epiphyseal vessels after closure of the growth plate) and the periosteal arterioles.

2.2 *The vascularization of diaphyseal cortical bone*

2.2.1 Topographic anatomy of the vascularization of the diaphysis of the rabbit femur

The *nutrient artery* of the rabbit femur arises from the lateral circumflex femoral artery. Over a distance of 2 cm it extends distally along the


A
B
C

lateral aspect of the iliopsoas tendon (Shim et al 1970) and enters the nutrient foramen This foramen extends obliquely to the knee and is localized on the medioposterior side of the femoral shaft, immediately distal to the lesser trochanter (Brookes & Harrison 1957) In the foramen the nutrient artery produces no branches Once in the medullary cavity after passing through the foramen it divides into ascending and descending vessels whose branches supply the bone marrow and the cortex with blood (figure 2) In the cortex arterioles which can be followed at best to a point halfway the cortex ultimately open up into the Haversian canals and Volkmann s canals which contain one or two endothelium lined vessels the size of a capillary (Brookes 1971 Rhinelander 1974)

Among the *metaphyseal* arteries the artery of the trochanteric fossa which arises from the medial circumflex femoral artery merits some attention because according to Brookes & Harrison (1957) and Brookes (1971) it could be a second afferent vessel for the diaphysis Th s artery enters through a foramen in the depth of the trochanteric fossa (Barone et al 1973) and divides into ascending branches which supply the greater and lesser trochanter as well as the femoral neck with blood The third trochanter (gluteal tuberosity of the femur) has no separate nutrient artery In addition branches of the trochanteric anastomosis and the arterial ring at the base of the femoral neck enter the metaphysis through many foramina The distal femoral metaphysis is supplied by numerous meta physeal arteries whose fairly thick branches penetrate the cortex through many foramina (Rogers & Gladstone 1950 Brookes & Harrison 1957 Brookes 1964)

The growing *epiphysis* has its own separate vascularization and until completion of growth the growth plate constitutes a vascular barrier between the epiphyseal and the metaphyseal system (Trueta & Morgan 1960 Koekenberg 1963 Trueta & Cavadias 1964)

It is probably only at the capillary level that the medullary arteries anastomose with the metaphyseal vessels after closure of the growth plate anastomoses with the epiphyseal arteries probably do exist but have not been demonstrated with any certainty (Brookes 1971) According to Brookes (1964 1971) this would imply that generally speaking under physiological conditions the diaphyseal metaphyseal and epiphyseal systems supply only their own region with blood According to Shim et al (1970) the nutrient artery accounts for at least 70 per cent of the circulation of diaphysis and bone marrow to which the other systems

→

Fig The c urse of the nutrient art ry and the metaphyseal and epiphyseal arteries in the rabbit femur (A, B) Transverse section (C) through a normal rabbit femur at the level of the passage of the nutrient artery through the cortex. Also note the a companying vein and arterioles and two nerves (HE x 63)

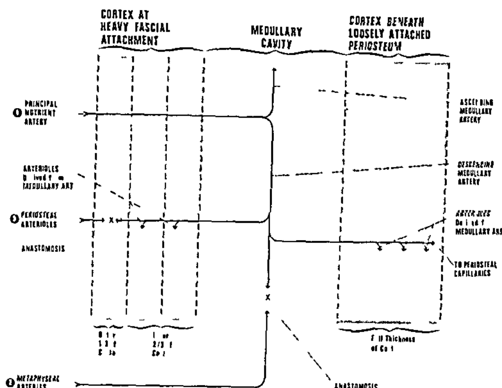


Fig. 3 Rhinelander's diagram showing the afferent vascular system of a mature long bone and its distribution

Components 1 2 and 3 constitute the total arterial blood supply to the diaphyseal cortex *Arrows indicate direction of blood flow*

Adopted from Rhinelander F W Circulation in Bone In The biochemistry and physiology of bone (G H Bourne ed) 2nd edition vol II pp 1 77 Academic Press New York 1972 (with the publisher s consent)

contribute about 30 per cent Under normal conditions each of the regi onal systems accounts for at least two thirds of the circulation of its primary supply region (Shim 1968) Trueta (*1959, 1968*) also refutes the *notion that these systems* consist of end arteries

On the capillary level there is a direct communication between the *periosteal* network supplied by the periosteal arterioles and the cortical capillaries At sites of muscle attachment (linea aspera) where the fibrous *periosteum is firmly anchored* to the bone, the intramuscular and the periosteal circulation merge The vascularization at these sites is more abundant than elsewhere in the periosteum (Brookes 1971 Rhinelander 1972, 1973)

A *large number of venous* sinusoids supplied by intracortical capil laries and medullary veins drain into a central intramedullary canal which

extends throughout the length of the diaphysis and drains into the two venous metaphyseal systems This central venous sinus is many times as wide as the nutrient artery but has a much thinner wall According to de Marneffe (1951) and Tilling (1958), there are no valves in it In the diaphysis the nutrient vein is *the sole ramification* (Brookes & Harrison 1957 Morgan 1959 Brookes 1971)

2 2 2 Functional anatomy

A more profound insight into the significance of the above described systems can be gained when we consider the contribution of each system to the cortical vascularization of a long bone *in the functional sense* Two relevant theories merit a more detailed discussion

2 2 2 1 Singular circulation concept

According to Brookes (1971) and Rhinelander (1972) the medullary circulation made up by the nutrient artery and also partly by the meta physeal arteries *through anastomoses on a capillary level is responsible* solely for the *afferent* cortical circulation They therefore maintain that, under physiological conditions the direction of flow in the diaphyseal cortex is centrifugal

The periosteal network plays a subordinate role in the afferent cir culation Possibly it contributes to the vascularization of a few superficial lamellae and this is probably the case in immature cortical bone lined with a richly vascularized periosteum (Rhinelander 1974) Rhinelander (1971 1973) attaches special significance to the periosteal arterioles in the vicinity of muscle attachments (linea aspera) which in this limited sector are believed to vascularize one-quarter to one third of the outer layers of compact bone The afferent vascular system is schematically represented in figure 3

Certainly in mature cortical bone the periosteal vessels are to be regarded as the final link in the *efferent* system The punctate haemor rhages which occur when periosteum is stripped off vital bone indicate that blood leaves the cortex here Venous blood *from the intermediate system* made up by Volkmann s canals and Haversian canals which constitutes the link between the afferent and the efferent system ulti mately drains through cortical venous canals into the *extraosseous* (pe riosteal) vascular network (Rhinelander 1972 1974) The periosteal *capillaries*, which communicate with the cortical capillaries of the super ficial cortical lamellae should also be regarded as a component part of the efferent system It is mainly the medullary sinusoids and the central

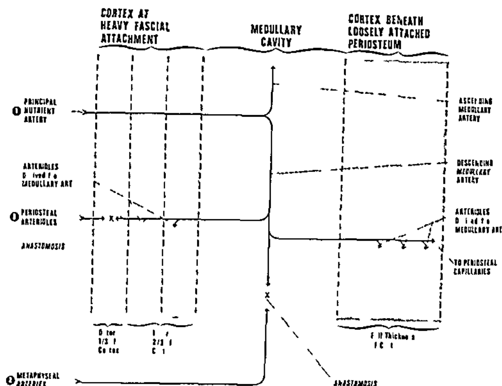


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A large number of *venous* sinusoids supplied by intracortical capil laries and medullary veins drain into a central intramedullary canal which

extraosseous arterioles penetrated the periosteal callus and vascularized osteoclastic removal of *necrotic* bone of the anterior and both lateral cortices This extraosseous circulation however, was transient and was reduced to normal proportions as soon as the normal medullary system had sufficiently regenerated When physiological conditions are interfered with *therefore* e g by interventions which completely block the medullary blood flow the direction of flow through cortex may be reversed by supply from the extraosseous system This new extraosseous circulation originates from soft tissues *surrounding the fractured* long bone and is a transient phenomenon (Rhinelander 1972) Gothman (1960a 1960b) as well has shown that the extraosseous supply comes from the soft tissues It disappears after regeneration of the medullary circulation

2 2 2 2 Dual circulation concept

The concept outlined above has been refuted by Trueta & Cavadias (1955 1964) Trueta (1963 1968) and Crock (1967) one of Trueta s co-workers They agree that the medullary system to which the nutrient artery contributes some 70 per cent while the metaphyseal and epiphyseal arteries account for the remaining 30 per cent is the most important system for the vascularization of the diaphyseal cortex But they restrict this to the inner two thirds of the compact bone maintaining that here the centrifugal flow encounters a centripetal flow originating from the periosteal vessels which in their opinion supply the outer one third of the cortex They hold that the efferent venous flow from the cortex is mainly through the medullary venous system This view was supported by the experiments of Langer (1876) Johnson (1927) Foster et al (1951) Gothman (1960a) Larson et al (1961) and Kockenberg (1963)

They advanced their hypothesis on the basis of experiments with young and mature rabbit radii in which the contribution made by each of the three sources of vascularization was determined by blocking the other two (Trueta & Cavadias 1964) For example after blocking the metaphyseal vessels and severing the nutrient artery in young and mature animals they found that the *outer one half to one* third of the cortex remained vital Johnson s findings (1927) were identical After severance of the nutrient artery and suppression of the periosteal blood flow by stripping off the periosteum and placing a thin polythene sheath around the bone one half to two-thirds of the inner cortex retained its vitality as long as the *medullary* circulation was taken over by anastomoses with the metaphyseal system If this did not happen (young animals) then total necrosis of the cortex resulted Similar results were reported after ligation of the nutrient artery and stripping of the periosteum in dog tibiae by Johnson (1927) in rabbits femurs by Foster et al (1951) and

venous sinus that are responsible for the drainage of bone marrow products These enter the medullary venous system by virtue of the permeability of the sinus endothelium, or by phagocytosis (Brookes 1971)

The above outlined concept of a centrifugal one way afferent circulation of cortical diaphyseal bone, originally advanced by Brookes & Harrison (1957) has been corroborated by MacNab (1957, 1958), MacAuley (1958), Jackson & MacNab (1959), and Nelson et al (1960) And it has been elaborated and substantiated in excellent micro angiographic studies by Rhinelander and his co-workers Suffice it here to present a summary of their principal results

Using fine granulated barium sulphate (Micropaque) as perfusion medium, the micro angiograms were studied microscopically and stereoscopically, and correlated to the histology of sections originating from the same tissue slices Throughout the healing process of non dislocated radial and ulnar fractures in mature dogs the medullary circulation, which had remained intact, continued to dominate External callus was supplied by extraosseous circulation (Rhinelander et al 1962) In the case of dislocated fractures, however, with interruption of the medullary circulation, an increased periosteal or extraosseous circulation was found initially to be the primary source of vascularization for the forming callus (Rhinelander et al 1968a) A typical feature was the course of these vessels perpendicular to the cortex Three to six weeks after fracture infliction, the medullary circulation had regenerated and resumed its prominent place in the blood supply to the callus and the devitalized fracture fragments This process proved to be as much accelerated as reduction of the fracture had been more exact In radial osteotomies followed by stable plate fixation reconstruction of medullary vessels was observed after only one week (Rhinelander 1968b 1972) The significance of the temporarily increased extraosseous vascularization gradually diminished and ultimately even the periosteal callus was supplied from the medullary circulation In the final stage of remodelling the normal pattern of vascularization returned, in which medullary vessels anastomosed with the periosteal vessels where they entered in the outer layers of the cortex at fascial attachments (Rhinelander 1968a 1968b) Even after destruction of the medullary circulation by osteotomy of the tibia (Rhinelander 1965) or the ulna (Rhinelander et al 1967) in dogs followed by insertion of a loose fitting intramedullary rod the medullary circulation proved to have enormous regenerative powers Insertion of a tight fitting nail after reaming of the medullary cavity through a femoral osteotomy resulted in temporary devascularization of the entire cortex with the exception of a small posterior sector near the linea aspera (Rhinelander 1973) The medullary circulation regenerated gradually and finally supplied the entire cortex with blood In the intermediate phase (8 weeks) of healing

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Finally, if only the nutrient artery was left intact, most of the cortex was found to retain its vitality, and only the outer one quarter showed necrosis This observation, too, confirmed Johnson's experiment (1927) Trueta found evidence substantiating the existence of a dual circulation in his observation (1963 1968, p 167) that two or even three vessels extended in opposite direction in a single Haversian canal This finding, however, has never been corroborated by other investigators (Brookes 1971) except Brånemark (1959) The most prominent critics of the dual circulation concept have been Brookes and Rhinelander

2 2 2 3 Refutation of the dual circulation concept

According to Brookes (1971) the observation of cortical necrosis following stripping of the periosteum and its replacement with a plastic sheath is understandable as a consequence of venous obstruction Rhinelander (1972) also criticized this way of suppressing physiological functions The remarkable fact is that the opponents make use of the same weapon i e both Brookes (1971, p 122) and Trueta (1968 p 168) find support for their arguments in a study by Nelson et al (1960) Referring to a vascular study of human tibiae these authors stated we agree with several recent studies (Brookes 1958 Brookes & Harrison 1957 MacNab 1957) that indicate that the periosteal vessels are of little significance in supplying arterial blood to the normal tibia

More recent studies also seem to decide the issue in favour of Brookes and Rhinelander The dominant importance of the medullary circulation was likewise convincingly demonstrated by Danckwardt Lillieström (1969), Danckwardt Lillieström et al (1970a) and Olerud & Danckwardt Lillieström (1971) Indian ink micro angiography and fluorochrome labelling were among the methods used in all the animal experiments next to be described

In the first study (Danckwardt Lillieström 1969) the medullary circulation of growing and mature rabbits was destroyed by reaming brushing or suction After these procedures the periosteal blood vessels initially proved capable of taking over nearly the entire cortical circulation As early as one week after the operation newly formed blood vessels had penetrated the medullary cavity Four weeks after the operation the reaction in the periosteal vessels had diminished and the medullary

circulation had sufficiently regenerated to revascularize the inside of the cortex After eight weeks there was no longer any difference in luminal width and depth of vascularization of the periosteal vessels between the test side and the control side In other words the pattern of vascularization had returned to normal In all animals the medullary cavity contained newly formed vessels which, in all growing rabbits and some 50 per cent of the mature animals were identifiable as thick walled arteries and in all animals as normal sinusoids After reaming and brushing of the medullary cavity in mature dog femurs the totally destroyed vascularization was found to have started regeneration within one week. Three weeks after the operation the revascularization of the medullary cavity was nearly complete and one week later it was complete The reactive periosteal vascularization was found to have returned to normal after six weeks

In another experiment (Danckwardt Lillieström et al 1970a) the medullary cavity of mature rabbit tibiae was reamed according to Kuntscher whereupon a dome shaped transverse osteotomy was fixed under compression with a specially designed medullary nail To promote rigid fixation of the osteotomy surfaces, the mid portion of the nail consisted of a massive metal cylinder with a length of 3 5 cm and a diameter which was 100 micra smaller than that of the burr last used However since the medullary cavity is not circular in cross section but triangular (proximal segment) or rectangular (distal segment) it was not quite occluded by the nail used This procedure resulted in total destruction of the intramedullary circulation At the level of the osteotomy the periosteal vessels too showed discontinuity over a distance of 1 cm on either side of the cut surface

The material was divided into two groups In the first group bone marrow was drained by suction through a separate aperture during reaming whereupon an osteotomy was performed and the nail inserted In the second group there was no suction of bone marrow during reaming Marked differences in general reactions severity of cortical necrosis revascularization and fracture healing were observed between the two groups An explanation of these differences will be offered on page 45

The vascular reaction did not differ in principle from that in the first experiment The first group (suction) showed quick restoration of the endosteal circulation blood vessels were observed in the medullary cavity after one week and the medullary circulation had largely regenerated after four weeks This process took a considerably slower course in the second (non suction) group

In a third experiment (Olerud & Danckwardt Lillieström 1971) dog tibiae were submitted to a double osteotomy with a Gigli saw removing an annular diaphyseal segment whereupon the cut surfaces were filed smooth Next the avascular fragment was re inserted and fixed in situ by means of a plate mounted under compression A study of the healing

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2 3 2 Cortical reactions

Within 24 hours of an intramedullary lesion or extraosseous blocking of the medullary circulation incipient necrosis of the endosteal cortex can be observed in the form of shrinkage and hyperchromasia of cell nuclei (Foster et al 1951 Trueta & Cavadias 1964 Richany *et al* 1965) After a week the endosteal lining has become *frayed* or has

process revealed that four-fifths of the revascularization of this fragment was accounted for by the destroyed medullary vessels, which had regenerated after four weeks (shortest observation period) The presence of the plate on the medial aspect of the tibia exerted no influence on this process, because the pattern of revascularization on the lateral aspect of the tibia was identical

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The evidence supplied by the above mentioned authors through their highly original experiments lends further substance to the assumption that the concept advanced by Brookes (1971), with the modification intro duced by Rhinelander (1972) for the vascularization of diaphyseal bone is the more plausible of the two concepts discussed Under normal con ditions the periosteal system is of subordinate importance for the cortical blood supply Under changed conditions however, the extraosseous ves sels prove to be of transitory importance After shaft fractures the med ullary circulation remains dominant After complete interruption of the medullary circulation the centrifugal direction of flow may be reversed temporarily and the extraosseous system of healing bone may become the principal source of revascularization of the cortex

2 3 *Description of the reactions to disturbed medullary circulation*

The circulation in the medullary arterial system, which has been de scribed above as the principal source of the vascularization of the dia physeal cortex can be partly or totally destroyed in various ways The ischaemia caused by intramedullary procedures has a number of typical consequences for the bone The reactions provoked in medullary cavity cortex and periosteum are so characteristic and reproducible as to justify a joint discussion of all relevant animal experiments carried out in the past The intensity of these reactions largely depends on the extent of the lesion, the animal species involved and the degree of maturity of the animals For a comprehensive review of the literature on intramedullary procedures we may refer to Danckwardt Lillieström (1969 pp 17 22) and Danckwardt Lillieström et al (1970a pp 3 12)

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2 3 3 The periosteal reaction

The periosteal reaction of *diaphyseal* bone to intramedullary procedures is likewise highly typical As described the primary reaction is an increase in the number of extraosseous vessels These are of greater than *normal luminal width* take a meandering course and extend perpendicular to the cortex *After* about two weeks this vascular proliferation is *most pronounced* (Danckwardt Lilliestrom 1969) it diminishes after four weeks and is reduced to normal proportions after eight weeks if healing of the fracture or osteotomy can take place (Danckwardt Lilliestrom 1969, Rhinelander 1973)

The osteogenic periosteal layer immediately shows marked cellular activity and reacts by the formation of new subperiosteal young bone This layer of new bone may cover the entire surface of the diaphysis Danckwardt Lilliestrom (1969) distinguished two morphological types a thinner layer of lamellar bone and a thicker layer of woven trabecular bone with its trabeculae perpendicular to the cortex *Cartilage* is found only at sites directly adjacent to an osteotomy or shaft fracture (*i e never beneath intact periosteum*) *This formation of new bone usually* attains its maximum after two to three weeks (Trueta & Cavadias 1955 Richany et al 1965 Danckwardt Lilliestrom 1969) In the course of subsequent weeks this young trabecular bone is gradually replaced by lamellar bone, and the demarcation between the old cortex and the new subperiosteal layer is effaced At the same time normalization of the extraosseous vascular reaction is observed

Radiologically the new bone initially has a cloudy appearance but eventually the structure becomes denser and the entire cortex proves to have increased in diameter (Trueta & Cavadias 1954 Kuntscher 1962 Slooff 1970 Lindwer 1972 Rhinelander 1973) An exception is the *experimental work of Gothman (1960b)* who after insertion of an intra medullary nail in mature rabbit tibiae observed periosteal hyperplasia in only a few instances and subperiosteal bone *apposition in* none in spite of marked extraosseous vascular proliferation Periosteal new bone formation has been given a variety of names Such designations as subperiosteal reaction (Richany et al 1965 Danckwardt Lilliestrom 1969) periosteal apposition (Lindwer 1972) provisional callus (Kuntscher 1940) external callus (Rhinelander 1973) new cortex (Anderson 1965 Danckwardt Lilliestrom et al 1970a) and secondary cortex (Slooff 1970) *all refer to the* same phenomenon

The diameter of the new bone layer can be quite considerable This too depends on the severity *of the lesion* and on the age and species of the test animal used An interesting fact in this context is the similarity reported by Richany et al (1965) and *Kelly (1968a 1968b)* to the periosteal bone apposition seen in the long bones in pulmonary hyper

disappeared, and one third to two thirds of the inner cortex has become necrotic (Trueta & Cavadias 1955, 1964, Richany et al 1965, Danckwardt Lilliestrom 1969) In these areas the bone lacunae are empty After a while the Haversian canals and the bone lacunae dilatate, and after two weeks the partial cortical necrosis attains its maximum (Trueta & Cavadias 1964, Richany et al 1965, Danckwardt Lilliestrom 1969)

As described in the first section of this chapter, extraosseous vessels react by a very marked proliferation and increase in luminal width, and such investigators as Danckwardt Lilliestrom (1969) have demonstrated this within 24 hours Soon after, new blood vessels are observed, which penetrate the cortex from the periphery and eventually also from the medullary cavity With these new vessels many „bone forming cells' appear (Brookes 1971) Although one might expect predominance of degradation of necrotic tissue in the early stages, yet few osteoclasts are observed (e g Brookes 1960b)

Large resorption lacunae appear, first in the middle one third of the cortex and then gradually also further down where the necrosis is deepest In the inner cortex these lacunae come to occupy so much space that fragments of dead endosteal bone can be rejected as sequestra into the medullary cavity (Trueta & Cavadias 1955, 1964 Danckwardt Lilliestrom et al 1970a, Slooff 1970, Lindwer 1972) Large vascular spaces, sometimes filled with bone marrow, are left behind in the inner part of the cortex (Brookes 1960, Richany et al 1965 Slooff 1970 Rhinelander 1973) These spaces produce the radiological features of osteoporosis (Brookes 1960, Rhinelander 1973) Brookes (1960) refers to this process as medullization and Slooff (1970) speaks of spongio zation' of the cortex

It should once again be clearly emphasized that the development of all these changes largely depends on the severity of ischaemia New endosteum begins to form after about six weeks (Richany et al 1965, Slooff 1970, Rhinelander 1973) and from this a new endosteal layer of lamellar bone is deposited At about the same time the process of resorption of dead cortical bone also attains its maximum intensity (Richany et al 1965, Danckwardt Lilliestrom 1969) According to Danckwardt Lilliestrom (1969 1970) bone remodelling takes place by infiltration of large broom shaped bundles of blood vessels which anastomose with pre existent intracortical vessels and of vessels preceded by osteoclasts so called cutter heads (Schenk & Willenegger 1963) Even though the majority of investigators report complete revascularization after about eight weeks, necrotic areas can be encountered even after many months (Foster et al 1951 Trueta & Cavadias 1955 Gustilo et al 1964, Richany et al 1965 Slooff 1970) to years (Lindwer 1972) This applies in particular to older animals in which the stimulus to recovery appears to become exhausted (Trueta 1968)

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Although considerable research has been devoted to the physiology of the blood circulation in bone and strong indications have been found that it is regulated via neural hormonal and particularly metabolic routes the exact mechanisms which control blood flow are still unknown (Shim 1968 Kelly 1968a Sim & Kelly 1970)

2.3.4 Bone marrow embolism

Danckwardt Lilliestrom (1969) maintained that the ischaemia resulting from vascular interruption is alone insufficient to explain the variations in the extent of subperiosteal bone apposition and cortical necrosis which can be observed even in the same section There should be another factor which could cause avascularity He was the first to demonstrate that intracortical bone marrow embolisms are an important cause of the above described changes and also that they can explain the occurrence of variations within the same bone after a medullary lesion As part of his experiment (cf page 38) he compared the percentage of avascular cortex with the amount of fat embolism demonstrated in intracortical vessels with the aid of Sudan 3 staining He found an unmistakable correlation He assumed that due to an increase in intramedullary pressure resulting from the intervention bone marrow was pressed into the Haversian canals and caused their obliteration The resulting intracortical block he reasoned contributed to the extent and intensity of the cortical necrosis and the reactive subperiosteal bone formation

Subperiosteally deposited bone marrow was also demonstrated When the bone marrow was removed by suction through a separate aperture in the distal metaphysis thus at the same time reducing the intra medullary pressure the vascular damage to the cortex was substantially less and revascularization of the entire cortex was demonstrable four weeks after the operation (Danckwardt Lilliestrom et al 1970b)

The experience gained was confirmed in the second experiment (cf page 39) Both cortical necrosis and subperiosteal bone formation were substantially reduced after reducing the intramedullary pressure and re moval of the bone marrow by suction It was also found that consoli dation of the osteotomy was considerably quicker when the intracortical circulation was not blocked by fat embolism

The occurrence of fat embolism following intramedullary procedures is not confined to the osteotomized bone Olerud et al (1969) found massive fat emboli in the femoral vein after reaming a rabbit tibia In the second experiment of Danckwardt Lilliestrom et al (1970a) described on page 39 the mortality due to pulmonary fat emboli was 11 per cent in the non suction group and 10 per cent of the animals showed unmistakable signs of systemic fat emboli but survived

trophic osteoarthropathy Although vascular changes are probably the substrate of this symptom, the exact aetiological mechanism has so far remained obscure (*Lipman & Massie 1964*)

Several explanations have been suggested for the newly formed subperiosteal bone after intramedullary interventions

1 It has been ascribed to chemical or physical irritation caused by the material of the intramedullary nail (Kuntscher 1940 1962) or to pressure exerted by the nail on the bone, or it has been regarded as a reaction to insufficient fixation of the bone fragments by the nail (L & J Bohler 1949)

2 Such investigators as Vanderhoeft et al (1963) reported periosteal bone apposition distal to an artificial arteriovenous fistula *in growing dogs They were unable to offer an explanation*

3 Richany et al (1965) contemplated the possibility of stasis and oedema, leading to local anoxia and prompting the formation of new bone

4 Zucman et al (1968) found bone marrow subperiosteally after reaming of rabbit tibiae and believed that this marrow, pressed through the cortical canals, could promote callus formation in the manner of an autograft

5 Kelly (1968b) produced periosteal tibial bone formation by placing a tourniquet around a thigh in growing dogs He observed increased pressure in the lateral saphenous vein and accelerated flow (clearance of ^{85}Sr) in the tibia He regarded increased pressure in veins and capillaries as the cause of the *formation of a new layer of subperiosteal bone*

6 Trueta & Cavadias (1955, 1964), who pointed out the prominent rule of the medullary circulation in the blood supply to the cortex, sought the primary cause in the ischaemia caused by intramedullary procedures, which provokes proliferation of periosteal vessels with accompanying new bone formation Koekenberg (1963) also believed that the cause was to be found in interruption of the circulation Brookes (1971, p 242) likewise believed the ischaemia to be the causative factor, and he made special mention of the changed intravascular pressure relations Local periosteal hyperaemia could be followed by an *increased cortical flow rate and changes in local oxygen and* carbon dioxide pressures

As Sim & Kelly (1970) pointed out, the oxygen demand at a local metabolic level could be an important factor in blood flow regulation

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5 Kelly (1968b) produced periosteal tibial bone formation by placing a tourniquet around a thigh in growing dogs He observ-ed increased pressure in the lateral saphenous vein and accel erated flow (clearance of ^{85}Sr) in the tibia He regarded in creased pressure in veins and capillaries as the cause of the formation of a new layer of subperiosteal bone

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As Sim & Kelly (1970) pointed out the oxygen demand at a local metabolic level could be an important factor in blood flow regulation

and, depending on the severity of the ischaemia produced this necrosis can involve almost the entire cortex The avascular bone marrow also becomes necrotic

During the repair phase the medullary circulation proves to have enormous regenerative powers and after a while it can entirely resume its function in the cortical blood supply This concludes the importance of the temporary extraosseous vessels as a collateral system and the rapid formation of young bone likewise subsides Thus subperiosteal bone layer matures and is partially incorporated in the old cortex. In the cortex dead bone is resorbed through invasion of new vessels and replaced by new bone for instance a newly formed endosteum deposits a layer of lamellar bone This process can take a very long time and is associated with the formation of large vascular spaces which may contain bone marrow and with sequestration of necrotic endosteal bone to the medullary cavity During the reorganization of the bone marrow after reaming macrophages and giant cells may be strikingly numerous Also scattered spicules of bone may form centrally in the medullary cavity to be eventually resorbed

Finally it has been found that an intramedullary procedure can lead to systemic fat or bone marrow embolism as a result of a local increase in pressure

The possible correlation between high intramedullary pressure and pulmonary fat embolism has also forcefully come to the fore in a different context Postmortems on patients who had died of acute cardiac arrest during a total hip or knee arthroplasty or hemiarthroplasty of the hip in which bone cement was used, revealed massive fat and bone marrow embolism in the lungs (Milne 1973, Dandy 1974, Herndon et al 1974)

This was initially interpreted as a possible side effect of the acrylic cement used, and special importance was attached in this respect to the lipophilic monomer (page 21)

Recent animal experiments carried out by Kallos et al (1974b) have confirmed, however, that the occurence of pulmonary bone marrow emboli is a direct result of an increase in intramedullary pressure No effort was made to establish the extent to which acrylic cement constituents too, may influence the occurrence of fat embolism (cf page 62)

2.4 *Summary*

Under physiological conditions the arterial afferent vascularization of the diaphyseal cortex of a long bone is dependent on the medullary circulation This is supplied by the nutrient artery (arteries) and in part by anastomoses with the metaphyseal arterial system The flow is centrifugal The periosteal vessels are thought to be of subordinate importance in this vascularization, only a small outer cortical sector near the sites of muscle attachment (linea aspera of femur) being supplied by periosteal vessels

Intramedullary procedures interfere with this pattern Depending on the severity of the lesion involved, the endosteal circulation is partly or totally interrupted thus depriving the cortical bone of its principal source of blood supply Moreover, the cortical ischaemia is also in part determined by the occurrence of intracortical bone marrow emboli These are as much more numerous as the intramedullary pressure during the intervention is higher (Danckwardt Lillieström and co workers) The reaction pattern of, in succession the diaphyseal cortical circulation the periosteum, the cortex and the medullary cavity is characteristic and reproducible It is largely dependent however, on the severity of the lesion, the increase in intramedullary pressure involved, the animal species used and the age of the animal

To some extent the extraosseous circulation of healing bone is capable of taking over the circulation in the diaphyseal cortex The afferent flow becomes temporarily centripetal Proliferation of the extraosseous vessels is accompanied by the formation of a subperiosteal layer of young bone over the entire cortical surface The inner cortical layers become necrotic

and depending on the severity of the ischaemia produced this necrosis can involve almost the entire cortex. The avascular bone marrow also becomes necrotic.

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CHAPTER 3

DESCRIPTION OF THE EXPERIMENT

3 1 *Objective, argumentation and design*

The objective of the investigation to be described was to establish, on the basis of animal experiments, which local side effects of acrylic cement cause the histological changes in cortical bone

In the analysis of these side effects of acrylic cement, they had to be distinguished from the reactions which occur in cortical bone after interruption of the medullary vascularization, as described in chapter 2

To begin with, the effect of interference with the medullary vascularization had to be studied in the model chosen for this study the rabbit femur Next it had to be established which histological changes occur in cortical bone when acrylic cement is implanted in addition For this purpose the two principal local side effects – those of the high polymerization temperature and the cytotoxicity of the monomer – had to be separately compared with the tissue reactions caused by interruption of the medullary vascularization

For a separate study of the high temperature effect we had to look for an acrylic cement which showed no or only a negligible rise in temperature at a constant monomer content The effect of this cement had then to be compared with the reactions caused in bone by commercial acrylic cement A simple subtraction would then give the tissue damage due to the effect of the high maximum polymerization temperature

For a separate study of the monomer effect an acrylic cement had to be found which contained a monomer excess but showed no rise in temperature For this too we had to establish the extra effect in tissue damage besides the effect of interruption of the medullary vascularization The reactions thus obtained had then to be compared with those produced by cement with a low maximum polymerization temperature and a normal monomer content

A supplementary study had to be made of the additional deleterious effect of monomer leaking from set cement (so called residual monomer 2-5 per cent which remains in cured PMMA page 21) The results thus obtained had to be compared with those produced solely by interruption of the medullary vascularization

In this manner it was argued it would be possible to gain from the rabbit femur an impression of which reactions in diaphyseal cortical bone are caused by

1 interruption of the medullary vascularization
2 cytotoxicity of an overdose of monomer
3 cytotoxicity of a very small amount of monomer which leaks from a set cement mass
4 high polymerization temperature of acrylic cement setting in situ

In order to separate these four effects different cement types were used (section 3 2) The test animals used in this study (section 3 3) were divided into seven different groups (section 3 6) after the operation (section 3 4)

In order to study the changes in the vascularization of diaphyseal cortical bone the lower limbs of the test animals were perfused with a fin granular barium sulphate suspension after sacrifice (section 3 7) Vascularization patterns were studied radiologically (section 3 8) and microangiographically (section 3 10)

The histopathological changes of cortical bone were studied after processing the femurs for histological (section 3 9) fluorescence microscopic (section 3 11) and autoradiographic (section 3 12) examination

3 2 *Cement types*

Three types of cement* were used in the experiment

a commercial acrylic cement (Palacos and Sulfix 6)
b a catalyst free acrylic cement obtained from one of the com mercial plastics (Palacos and Sulfix-6)
c a modified acrylic cement (*Sulfix-6 with CMC gel*)

3 2 1 Palacos and Sulfix 6

The properties of Palacos which has been used in Europe for many years can be presumed known The ratio polymer powder with radio-paque contrast medium monomer fluid is 2 1 The conventional pack ings contain about 40 g powder and 20 ml fluid

Palacos® and Sulfix® were respectively supplied by Kulzer & Co GmbH 638 Bad Homburg v d H., Germany and Sulzer Bro Ltd, -CH-840 Winterthur Switzerland.

Sulfix-6 is a new commercial product described by the manufacturer as different from products marketed earlier (Palacos, CMW and Simplex P) in that it has a number of improved properties It is somewhat more finely granular and has a longer working time (Debrunner and Wett stein 1975a), because 15 per cent of the fluid consists of the co polymer n butylmethacrylate, there is an indication of a (not significantly) lower *maximum polymerization temperature at the cement surface* (Debrunner 1974), and its lower porosity (Semlitsch 1975) is believed to give it slightly better mechanical properties than the other commercial acrylic cements There are no differences in monomer release (Debrunner and Wettstein 1975b), tissue toxicity of the cured product (Semlitsch 1973) and volumetric changes during polymerization (Debrunner 1975) As in Palacos, zirconium dioxide has been added to the polymer powder as radiopaque contrast medium The ratio polymer powder monomer fluid is 5 2 Conventional packings contain 40 g powder and 16 ml fluid

3 2 2 Catalyst free „acrylic cement"

As described in section 1 of chapter 1 polymerization occurs by virtue of the presence of an initiator in the powder and an activator in the fluid When the benzoyl peroxide (initiator) is washed out with methanol, no polymerization reaction occurs the end product becomes neither warm nor hard One obtains a rubber like substance which remains malleable for days but, exposed to air, sets after about a week due to evaporation of the monomer, *this is accompanied by an unmistakable decrease in* volume We had the disposal of polymer powder and monomer fluid without catalyst system Since no polymerization takes place in this „cement an overdose of monomer remains in it (about 30 volume per cent) By eliminating the high polymerization temperature we could sepa rately study the cytotoxic effect of this excess of monomer

3 2 3 Modified acrylic cement Sulfix 6 with CMC gel*

Next we looked for a cement *which would enable us to eliminate* the factor polymerization temperature Initially we succeeded in reducing the maximum polymerization temperature by adding water when mixing the cement Due to phase separation however no homogeneous distri bution of water and cement could be obtained Moreover the mixture could not be used in the syringe By using a high viscosity gel J R de Wijn Chem E (Department of Dental Materials Nijmegen University)

* Sulzer Bro Ltd Winterthur Switzerland patents pending

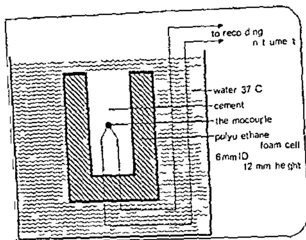


Fig 4 Arrangement for measuring the maximum temperature in polymerizing cements

succeeded in reducing the maximum temperature without affecting the manageability of the mixture

To the Sulfix 6 powder and fluid in the ratio indicated by the manu facturer an amount of high viscosity CMC gel was added to make a mixture with 36 5 per cent (weight) gel The polymer powder CMC gel monomer fluid ratio was 5 4 2 Gel phase and resin phase in this mixture remained well distributed which is to say that the gel formed a smooth outer layer on the surface

In the centre of a test rod (fig 4) of 0 5 cu cm the maximum poly-merization temperature of this cement remained between 50° and 60° C In a similar test rod the commercial cement attained a temperature of 80 100° C (fig 5) In a globule of CMC cement kept in the hand, hardly any rise in temperature could be felt and the temperature in vivo could be expected to be even lower because of the favourable heat release at the cement/bone interface (Debrunner 1975 Biehl et al 1974) There were therefore sound reasons to presume that the temperature effect had been drastically reduced

It was likewise to be expected that the percentage of nonpolymerizing monomer would equal or slightly exceed (due to the low polymerization temperature) that in the conventional commercial bone cements

The biphasic mixture of gel and cement will develop what may be described as a gel filled porosity and this of course influences the me chanical properties also Since the aqueous gel phase is biodegradable (dissolves) it could be maintained that *a porous cement* had been ob-

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Fig 6 Incident light microscopy (60 x) In the modified cement (above) the dark areas represent the gel phase and the lighter areas the resin phase 35 per cent *porosity*
In the commercial cement (below) the dark areas represent the normal porosity as a result of air inclusion and marked evaporation of monomer *during polymerization* the lighter areas represent the resin phase 5 per cent porosity (with acknowledgement to J R de Wijn Chem E)

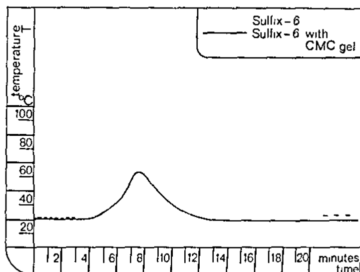


Fig 5 General shape of temperature time curve in laboratory tests The polymerization time is the same for both types of cement

tained[1] The pores communicated and so formed a system with so called open porosity, in contrast with the closed porosity of commercial acrylic cements (fig 6) Porous implant materials, with all their advantages and disadvantages are currently in the centre of interest For a brief discussion we refer to chapter 5 For the design of this study it was of primary importance that a manageable cement was obtained in which the high maximum polymerization temperature was eliminated while the percentage of non polymerizing monomer remained about the same

The gel was a solution of 5 per cent sodium carboxymethylcellulose (CMC)* in water A 1 per cent aqueous solution of this CMC has a viscosity of 400 centipoise (CPs) The viscosity of the 5 per cent CMC gel used as measured with a Brookfield viscosimeter at 3 rpm was about 120 000 CPs

Carboxymethylcellulose is extensively used in the foods industry as wallpapering glue in rayon yarns and as constituent of synthetic detergents In pharmacology it is used as adjuvant in oral preparations and eye lotions and as catheter lubricant So far as could be established its toxicity to vascularized tissues is negligible

3 2 4 Sterilization

The polymer powder received from the manufacturer in the unsterilized form (Palacos and Sulfix) was divided into 10 g fractions which

* Nymcel ZHF30 Nijmegen Netherlands

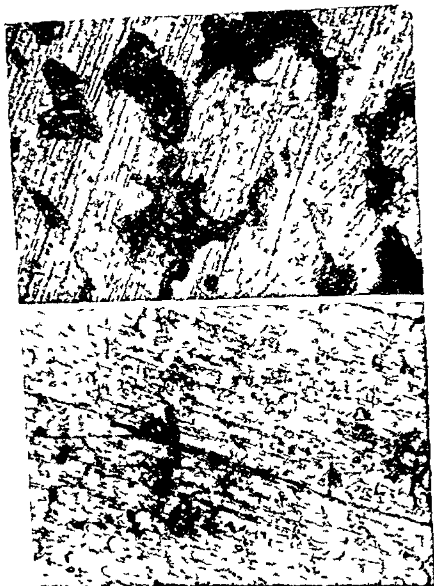


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were double packed and gas sterilized (ethylene oxide) In view of the toxicity of ethylene oxide (O'Leary and Guess 1968), the sterilized pow der was not permitted to be used until 2 x 24 hours after sterilization (O Leary et al 1968, Zagar 1972) No bacterial growth was ever found in samples which were bacteriologically examined The monomer fluid supplied by the manufacturer was sterile, and was divided into pre sterilized bottles under aseptic precautions The amounts for Palacos and *Sulfix 6* were *5 ml and 4 ml*, respectively

The CMC solution in water was sterilized in saturated water vapour at 100° C in a glass jar for 30 minutes and then, in a semi liquid state divided into sterilized eye ointment tubes under aseptic precautions Be cause the viscosity diminished during sterilization due to thermic deg radation of the CMC polymer (breakdown of chain length) we used a high viscosity CMC sodium gel to start with This ensured that the product obtained after ultimate mixing with Sulfix 6 had the desired consistency

3 3 *Test animals*

The test animals used in the experiment were 166 young adult rabbits of the New-Zealand White strain They were selected because a large number of animals were needed and because adequate data are available on the vascularization of the rabbit femur The animals were about 4 months old, in good health, averaging 2465 g (range 1900-3400 g) body weight immediately before operation All were obtained from the same breeder and arrived at the animal laboratory at least 14 days before being used in the experiment They were accommodated in individual cages with grid floor, received water *ad libitum and* were *fed a standard diet* (standard mixture L K = 01 Hopefarms n v Woerden, Netherlands)

The rabbits were randomly taken from the various litters and divided over the various groups (section 3 6) The sex distribution was likewise at random

In 4 month old rabbits the growth plates have not yet closed The expected total longitudinal growth of the average rabbit femur is indicated in fig 7 The curve shown corresponds with the longitudinal growth pat tern of the rabbit tibia indicated by Heikel (1960) in which the initially linear growth curve likewise declines after 100 days

3 4 *Operative technique*

The animals were fasted during 24 hours preceding the operation Anaesthesia was induced by intravenous injection of 0 5 mg atropine and 30 mg/kg pentobarbital sodium (Nembutal S A Abbott n v Amster

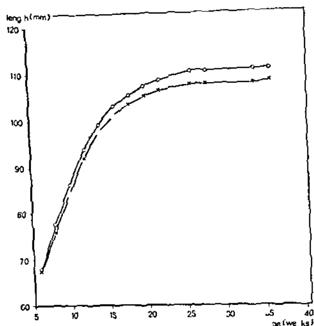


Fig 7 Longitudinal growth curves of the rabbit femur At age 6 8 10 12 14 16 18 20 22 26 28 34 and 36 weeks, X ray were made of both femurs in a measuring box especially designed for this purpose under general anaesthesia. In this box the distances between focus and plate (66 5 cm) and between femur and plate (5 7 cm) remained constant On an OPTOCOM measuring table the coordinates (most distal end of lateral femur and most proximal end of greater trochanter) were established, where upon the computer calculated the distances and plotted the mean curve for both femurs of 5 male (topcurve) and 5 female (bottomcurve) New Zealand White rabbits For calculation of the true femoral lengths, the values indicated in the two curves must be corrected by factor 0 914 (from a doctoral thesis by H. M van de Sandt Circumferential sectioning of the periosteum in press)

dam) At the same time each animal received 50 mg/kg oxytetracycline (Terramycin Pfizer Ltd Sandwich England) by intravenous injection as fluorochrome

After intubation the entire left hindleg was shaved and washed with Bethadine iodine soap and 70 per cent alcohol The animal was put on the table on its right side lying on a water heated mat and connected to a Keuskamp Amsterdam Infant Ventilator for ventilation with a mixture of oxygen and nitrous oxide (ratio 1 2) and 1 per cent halothane (Fluothane)

Sterility was ensured by observing precautions normally taken for any surgical intervention The left thigh was painted with iodine and after sterile

were double packed and gas sterilized (ethylene oxide) In view of the toxicity of ethylene oxide (O Leary and Guess 1968), the sterilized powder was not permitted to be used until 2 x 24 hours after sterilization (O Leary et al 1968, Zagar 1972) No bacterial growth was ever found in samples which were bacteriologically examined The monomer fluid supplied by the manufacturer was sterile, and was divided into pre sterilized bottles under aseptic precautions The amounts for Palacos and Sulfix 6 were 5 ml and 4 ml, respectively

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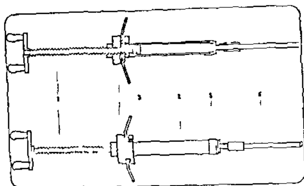


Fig 8 Schematic representation of the modified Impregum® syringe for cementing the medullary cavity Screw spindle (1) with p ton (2) Cap (4) with bayonet jo nt fitting the cylinder (3) Threaded nozzle with conical end and hose connection (5) Teflon tubing (6) with an external diameter of 4 mm and an internal diameter of 2 mm

of monomer evaporating slowly in small amounts of set acrylic cement could thus be studied The operation was completed as indicated sub a)

c *Cementing* of the medullary cavity Bone cement (cf section 3 2) was prepared and in a dough like state pressed into a modified Impregum® syringe (ESPE GmbH Seefeld Austria) The syringe had been modified (fig. 8) to correspond with the cement syringe designed for hip surgery by Slooff (1969 1970) Syringe and Teflon tubing could be sterilized With the aid of a filler ring and plastic piston the cement was pressed into the cylinder until this was three-quarters full The syringe was then mounted and the screw spindle tightened until the acrylic cement emerged from the end of the tubing At that time the suction tube was replaced by the Teflon tubing of the cement syringe which was inserted into the medullary cavity as far as the femoral condyles Slowly rotating the syringe the entire medullary cavity was filled from the distal to the proximal end while at the same time the syringe was slowly retracted This did not require much force because the tubing was pushed proximally by the cement filling the femur (fig 9) Usually a thin trickle of cement escaped from the vent hole and remnants of bone marrow (if any) escaped with it. The insertion and filling were done slowly so that it took about 1 minute for the femur to be filled entirely Dependent on the size of the animal the amount of cement introduced was 2 3 ml During this phase of the operation care was taken to ensure that the anaesthetic

draping, an incision of 1-2 cm was made over the greater trochanter This was stripped of its periosteum, and a manual drill with a diameter of 3 2 mm was then used for cautious reaming of the medullary cavity * The drill was introduced over a distance of 3 cm, whereupon the correct direction was determined with a guide-wire Drilling was then continued as far as the femoral condyles The medullary cavity was further widened with the aid of a second manual drill with a diameter of 4 0 mm Owing to the physiological antecurvature of the femur, reaming with this straight drill was possible only to about halfway the medullary cavity It was needed, however, because otherwise the Teflon tubing used for suction and cementing could not be readily inserted as far as the knee Via a second incision of 1 cm immediately proximal to the lateral femoral condyle, the periosteum was opened by means of a small longitudinal incision, the capsule was slightly pushed back and a burr hole was drilled in the cortex with a manual drill (burr diameter 1 6 mm)

A length of strong Teflon tubing (external diameter 4 mm, internal diameter 2 mm) was then inserted into the medullary cavity from the proximal end, connected with a suction tube and slowly pushed down as far as the knee The diameter of this tubing was such that some pressure was required to insert it and it was felt to scrape along the wall of the medullary cavity The tubing pushed most of the bone marrow away in front of it and this escaped through the vent near the lateral femoral condyle Bone marrow remnants were sucked away by moving the Teflon tubing up and down five times until only clear blood was being sucked up After reaming and suction of the medullary cavity the operation was continued in one of the following three ways

a *Closure* Fascia and skin of both incisions were closed with linen sutures while the animal was recovering from the anaesthesia After detubation the animal was placed on a blanket near a radiator in order to prevent heat loss

b *Insertion of a loose fitting intramedullary rod* (Palacos®) A Palacos rod (diameter 3-4 mm, length 6 7 cm) was inserted from the proximal end and pushed in as far as the femoral condyles Any part still protruding was cut off with bone forceps The rods had been fashioned under sterile precautions a few hours earlier and had been kept sterile They could be expected to contain 2 5 per cent residual monomer (Smith and Baines 1956 Kutzner et al 1974a) The possible tissue damaging effect

* The use of a powered drill was deliberately avoided because thermic damage cannot be excluded with any certainty (Dankwardt Lilliestrom 1969 Matthews and Hirsch 1972 Rhinelander 1974)

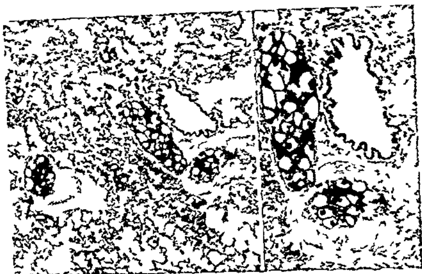


Fig 10 Bone marrow embolism Photomicrograph of represer ive lung area (x 40) The dark material is Sudan 4-stained fat and bone marrow
The arrow points to a possible shunt between the arterial and venous system The detail (x 70) is of an artery in parabron hial localisation with a dilated small branch The wall of this branch is markedly thinned

which the medullary cavity was filled with Palacos after reaming and suction The operative technique initially used differed from that de scribed in section 3 4 as used in the ultimate experiment no vent hole was drilled near the lateral femoral condyle and the tubing of the syringe was not filled with cement to its very end.

In the first 7 animals operated on peroperative and immediate post operative mortality was high One animal had to be sacrificed because of a femoral shaft fracture which had occurred during reaming of the medullary cavity During or shortly after introduction of the cement three animals showed pale sclerae and dilatation and downward displace ment of the pupil as well as an irregular heartbeat Ventilation with pure oxygen and external heart massage brought no improvement Spontaneous respiration was not resumed There appeared to be a respiratory stand still the irregular heartbeat continuing for a few more minutes

During postmortem examination of the first animal to die *in this* manner no macroscopical changes were seen However when the right ventricle was opened under water there emerged air bubbles That air embolism had occurred was not surprising because *an air column of* about 7 cm length was introduced under pressure into the vascular bed which had already been damaged as a result of the reaming This expe

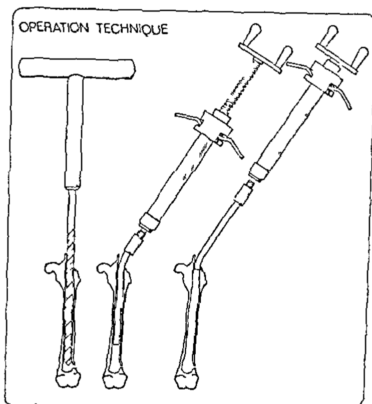


Fig 9 Operative technique Explanation in text pages 56 57

was not allowed to become too deep The operation was completed as outlined sub a)

All operations were performed by the author, assisted by a biotechnician who gave the anaesthetic and an intern in orthopaedics The operation *was simple and readily reproducible In all cases without exception the leg thus treated was capable of normal weight bearing after the* operation this could be checked because the animals had to stand erect on their hindlegs in order to reach their drinking bottle There were no infections in the area of the operation, and no wound dehiscence occurred

3 5 *Preliminary experience and explanation of the operative technique used in the ultimate experiment*

3 5 1 Introduction

In order to gain an impression of the problems which might pose themselves during the experiment a test group of 25 rabbits was used in

by a few tenths of an atmosphere during insertion of the suction tube and during suction A marked increase in intramedullary pressure occurred while the cement was being introduced It was found that the pressure could be regulated by adjusting the rate of introduction of the cement The mean rise in pressure in the 12 animals was up to 1 4 atmosphere During rapid introduction of cement the pressure could rise to 2 5 atmospheres (end of the manometer scale) The increase in pressure sometimes persisted for some considerable time once the medullary cavity was completely filled (partly because the apertures in the screw were as a rule also filled with acrylic cement)

In each of the 12 animals the ECG showed accelerated sinus rhythm and lowering of the ST complex indicative of coronary insufficiency No straightforward correlation was established between the level of intra medullary pressure measured and the severity of the ECG changes The 6 animals in which the system leaked showed no ECG changes Three animals in which the pressure rose to 1 8 2 3 and 2 5 atmospheres, respectively su cumbed as a result of histologically verified pulmonary fat and bone marrow embolism In these animals the ECG features were those of a changed electrical heart axis increasing atrioventricular block with nodal extrasystoles repolarization disorders and intraventricular conduction disorders (broadened QRS complex)

3 5 3 Discussion

The method used to measure intramedullary pressure had some un mistakable disadvantages a manometer is not a precision instrument registration is not possible the occlusion ensured by the screw in the bone was often insufficient (with as a result a pressure measured too low) and the apertures in the screw filled with bone marrow remnants and some times with acrylic cement These measurements were exclusively carried out to gain an impression of the rise in intramedullary pressure and of the extent to which it could be regulated by quicker or slower tighten ing of the screw spindle of the cement syringe

Even though these results which closely resemble those reported by Marsman et al (1975) warrant no absolute or generally valid conclusions yet they helped in setting up the ultimate exp riment After reaming of the medullary cavity a venthole was drilled immediately proximal to the lateral femoral condyle in all animals used in the ultimate experiment This was done in order to

1 prevent an excessive rise in intramedullary pressure
2 prevent massive pulmonary embolism
3 ensure more complete removal of medullary contents

rience taught us therefore to fill the entire length of Teflon tubing with cement before introducing the cement syringe

Of the other two animals, one developed irreversible shock shortly after insertion of the Teflon suction tube, and the other died shortly after introduction of the cement The deaths of these two animals (with macroscopically normal parenchymal organs at postmortem), however, could not be explained by an air embolism In these animals massive fat and bone marrow embolisms were found in the lungs when frozen sections were stained with Sudan 4 (fig 10)

These complications did not occur when a lateral vent hole was drilled in the distal segment of the femur, whereupon the cement was slowly introduced In view of studies by Danckwardt Lilliestrom (1969) and Danckwardt-Lilliestrom et al (1970a, 1970b), it seems plausible that the cause of these fat embolisms had to be an increased intramedullary pressure during the operation In order to estimate the maximum possible increase in intramedullary pressure during the operation, this pressure was measured via a simple system in the next 18 animals It was also decided to monitor the ECG routinely

3 5 2 Determination of intramedullary pressure with simultaneous electrocardiographic registration

3 5 2 1 Method

A burr hole was drilled immediately proximal to the lateral femoral condyle, a screw thread was tapped and a modified hollow cortex screw (ASIF)* with a length of 20 mm was inserted and tightened as far as the opposite cortical layer Two apertures were made at the end of this screw Via a water filled cannula, the screw was connected with a likewise water-filled standardized manometer The increase in intramedullary pressure was measured during insertion of the suction tube, suction of the medullary cavity, introduction of the cement and setting of the cement

Throughout the operation, standard leads 1 2 and 3 on 4 legs were used to register the heart action with the aid of a Mingograf 81 electrocardiograph (Elema Schonander Stockholm Sweden) Arterial blood pressure, central venous pressure cardiac output and blood gas values were not registered

3 5 2 2 Results

In 6 of the 18 animals the screw proved to occlude inadequately and no pressure was measured In the remaining 12 rabbits the pressure rose

* Association for the Study of Internal Fixation Davos Switzerland

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1 prevent an excessive rise in intramedullary pressure
2 prevent massive pulmonary embolism
3 ensure more complete removal of medullary contents

4 minimize the risk of intracortical bone marrow embolism which, through obliteration of vascular canals, can greatly contribute to cortical necrosis (Danckwardt Lilliestrom et al 1970b)

In the elegant experiment which Kallos et al (1974) published after completion of this study, the direct correlation between high intramedullary pressure and pulmonary fat embolism was incontrovertably demonstrated

During digital introduction of acrylic cement and a stainless steel rod in the cement mass into dog femurs they measured intramedullary pressures of 290 900 mm Hg with the aid of a tracer (^{99m}Tc macroaggregated albumin) injected into the medullary cavity they established that medullary contents appeared in the lungs within 10 120 seconds When a vent hole was made in the femur the intramedullary pressure did not rise beyond 1 93 mm Hg and no increase in radioactivity was observed in the lungs Histological examination revealed fairly large fat globules in the lungs of dogs with non vented femurs whereas only a few small globules were observed in the lungs of dogs whose femurs had been vented previously

3 5 4 Conclusion

In view of preliminary experience gained with 25 rabbits used as a test group we opted for drilling a vent hole in the lateral distal femur in all animals used in the ultimate experiment

3 6 *Division into groups*

The animals were classified according to type of operation and type of acrylic cement used (table 1) The seven groups included 18 animals each (table 2) Intercurrently deceased or disqualified animals (section 3 13) were replaced As described in section 3 4 the operation was always performed on the left femur, the right femur serving as control An exception was made for groups 1 and 3a, which represent bilateral

Table 1 Grouping according to type of operation

Group	Type of operation
1	Reaming and suction of medullary cavity (RS)
2	RS + Palacos rod
3a	RS + commercial acrylic cement (Palacos)
3b	RS + commercial acrylic cement (Sulfix 6)
4a	RS + acrylic cement (Palacos) without catalyst
4b	RS + acrylic cement (Sulfix 6) without catalyst
5	RS + modified acrylic cement Sulfix 6 with CMC gel

Table 2 Classification of numbered animals per group and per period of observation

Period of observation	Group 1	2	3a	3b	4a	4b	5
week 1	R 6417 R 6420)	6538 6546	L 6417 L 6420	6439 6440	6401 6402	6428 6429	6474 6475[2])
week 2	R 6412 R 6413[1])	6600[1]) 6542	L 6412 L 6413	6432 6453[1])	759 760	6405[1]) 6406	6476[1]) 6477
week 3	R 6410 R 6411[3])	6595 6545[3])	L 6410[3]) L 6411	6451 6452	754 755	6409 6414[3])	6492 6493[3])
week 4	R 6422 R 6423	6596 6544	L 6422 L 6423	6449 6450	6403 6404	6415 6416	6494 6495
week 5	R 6418 R 6419	6597[2]) 6543	L 6418 L 6419	6430 6431	752 753	6426 6427	6496 6497
week 6	R 6424[1]) R 6425	6598 6541[1])	L 6424[1]) L 6425	6435 6438[3])	750[1]) 751	6408 6445	6490[1])[3]) 6491
week 7	R 6443[4]) R 6444	6599 6540	L 6443[4]) L 6444	6436 6448[4])	6454 6455	6446 6447[4])	6484 6483[4])
month 3	6462 6467[1])	6539[1]) 6537	6441[1]) 6442	756 757	6548 6561[1])	763 764	6482[1]) 6485[1])
month 6	R 748 R 747	6473 6536	740 L 747	L 748 741[1])	6503 6504[1])	6501 6502	6486[2]) 6487[1])[3])
month 9			737 326				
month 12			328[1]) 357				
month 24			358[1]) 735				

Figures in chapter 4

[1]) Photomicrograph histological section
[2]) Macroangiogram
[3]) Microangiogram
[4]) Fluorescence photomicrograph

4 *minimize the risk of intracortical bone marrow embolism* which, through obliteration of vascular canals, can greatly contribute to cortical necrosis (Danckwardt Lilliestrom et al 1970b)

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5	RS + modified acrylic cement Sulfix 6 with CMC gel

after operation and once a week thereafter The purpose was to evaluate whether the method of cementing was sufficient (i e whether the entire femur was filled with cement) and to establish whether fractures had occurred during the operation or became manifest after the operation In addition it was expected that the femurs treated by operation would increase in circumference as has been the case in the studies of Slooff (1970 1971) who introduced acrylic cement into the medullary cavity in dogs The radiological follow up was made to establish whether the same could be observed in rabbit femurs

3 8 1 1 Method

The animal was kept still by intramuscular injection of 0.5 ml/kg Hypnorm (Philips Duphar) and 0 5 mg atropine tied to a specially designed stand and submitted to AP radiography The roentgen apparatus used was a Philips Super Practix and the film a Kodirex Autoprocess (no screen)

3.8 1 2 Results

The medullary cavities of all femurs except two were entirely filled with acrylic cement. In one animal an avulsion fracture of th femoral diaphysis was observed which had been overlooked at operation The mean increase in femoral circumference was small A thin low-contrast layer of periosteal bone apposition was usually visible along the entire cortex from the second postoperative week on The layer attained its maximum thickness after 3 weeks and in the 14 animals with completely cement filled medullary cavities, caused a mean increase in circumference of 9 per cent, as measured on a fixed point at the centre of the diaphysis. Subsequently the density of this new bone increased, and no further radiological changes occurred after 7 weeks.

3 8 1 3 Discussion

The enormous bone apposition which Slooff (1970 1971) observed in cemented dog femurs was not found in rabbit femurs Since the above described radiographic method was rather cumbersome since the animals biorhythm was being disturbed every week and since the information obtained was of little value these radiographs were not included in the ultimate experiment

3 8 1 4 Conclusion

As weekly radiographic follow up failed to yield anything of value it was abandoned for the animals in the ultimate experiment Immediately after operation a radiograph was always obtained to make sure that the entire medullary cavity was filled with cement and to ascertain that no fracture had occurred

operations operations on the left femur formed group 3a, and operations on the right femur formed *group 1* The animals were paired off for sacrifice 1, 2, 3, 4, 5, 6, 7 weeks and 3 and 6 months after operation This means that for every survival period 2 animals per group were available for examination Finally, 6 animals were kept alive until 9, 12 and 24 months after the operation (table 2) They were the 6 animals of the test group in which determination of intramedullary pres sure had shown no rise due to leakage along the screw It could therefore be assumed that no significant rise in intramedullary pressure had oc curred The acrylic cement used in these cases was Palacos (section 3 5 2)

3 7 *Sacrificing technique*

After intravenous injection of 50 mg (5000 IU) heparin, the animals were sacrificed by intravenous injection of an overdose of pentobarbital sodium (Nembutal) Immediately after cardiac arrest the abdominal cavity was opened and the aorta was cannulated at the level of the renal arteries with a plastic cannula inserted almost as far as the bifurcation The aorta was ligated proximal to the site of cannulation The inferior vena cava was opened From a constant height of 100 cm (the most common physiological perfusion pressure) irrigation was effected with 1 litre phys iological saline The cannula was then connected with an infusion flask filled with a Micropaque® suspension * This was a 6 per cent barium sulphate solution made from Micropaque 70 per cent W/W fine granular barium sulphate and 35 g sodium citrate in 1 litre physiological saline The first 300 ml of this solution could be run in quickly, the rest followed at a steady drip As a rule, the suspension freely escaped from the inferior vena cava after about 1 minute It took about 90 minutes for perfusion of the total amount of 1000 ml Micropaque suspension to be completed The perfusion pressure was not measured Next both femurs were ex-articulated in hip joint and knee joint leaving an ample muscular cover in order to leave the periosteum intact The bones were immediately numbered, packed in plastic bags and deep frozen to –18° C

3 8 *Radiological technique*

3 8 1 Radiographs during the period of observation

In the animals of the test group, radiographs of the pelvis and both femurs were made by a standard method before operation immediately

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* Micropaque® (Microtrast) Oesophageal Cream is supplied by Damancie & Cy Ltd Slough (Bucks) Great Britain

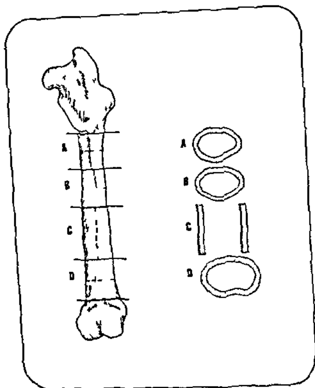


Fig 11 Schematic representation of segments used for decalcified and non decal cified sections

decalcified sections thus obtained were embedded as a histological section with a non fluorescent adhesive (DPX) and studied with the fluorescence microscope (section 3 11) The procedure described caused disappearance of acrylic cement from the bone by dissolution in trichloracetic acid toluene chloroform xylol and acetone

3 10 *Microangiography*

To obtain microangiograms of the non-decalcified sections from seg ments A B C and D of left and right femur use was made of a micro-radiogram arrangement with a Philips self rectifying X ray generator type PW 1008 and Kodak spectroscopic safety film type 649-0 (20 min 20 kV 30 mA) The sections were placed directly on the film the distance from the tube being 20 cm The microradiograms obtained were placed on a slide and examined with the light microscope

3 8 2 Postmortem radiographs

To assess the degree of filling of vessels with Micropaque, radiographs were made in two directions of all deep frozen femurs, using mammo graphy equipment with a molybdenum anode Very fine grained industrial roentgen film was used so that enlargements were possible if required This technique has been found very suitable for evaluation of bone structure (Meema et al 1972, Hendriks 1975)

3 9 *Histological technique*

Of the deep frozen femurs with soft tissue lining only the diaphysis and a small part of the lower methaphysis were used This was manually cut into 7 transverse segments of about 0 75 cm thickness, which were numbered A, B, C and D from proximal to distal end Segment C was bisected longitudinally, thus giving a total of 8 bone fragments Of each segment A, B, C and D, one half was decalcified for paraffin processing and the other half was not decalcified but destined for embedding in plastic The segments A, B and D were cut into transverse and segment C into longitudinal sections (fig 11) The procedure to obtain paraffin sections was decalcification during 2 days in 5 per cent trichloracetic acid (which is also a fixative fluid which ensures persistent stainability) followed by washing with 90 per cent alcohol for 1 hour and then de-hydration with 70 per cent alcohol, 80 per cent alcohol and 90 per cent alcohol and toluene (each during 24 hours), finally followed by degreasing with chloroform during 12 hours Next, the tissue fragments were soaked in paraffin during 12 hours in an incubator at 60° C to ensure evap oration of the chloroform The fragments were then embedded in paraffin and a Leitz microtome was used to cut 5 micra sections These sections were stained with haematoxylin eosin and according to Goldner (Romeis 1968, Schenk et al 1969) The Goldner stain gives non mineralized connective tissue (e g osteoid) an orange red colour bone stains green, cells black, cytoplasm orange and muscular tissue reddish violet

The procedure to obtain the non decalcified sections was fixation in 70 per cent alcohol during about 16 hours followed by dehydration with 80 per cent alcohol 96 per cent alcohol 100 per cent alcohol acetone and toluene (each during 24 hours) The slices were then embedded in methyl methacrylate and after curing cut into 110 micra sections with a diamond section cutting machine (instrument workshop Department of Dentistry, University of Groningen) These sections were polished on both sides (Kent MK_2 polishing machine Engis, Alphen a/d Rijn, Netherlands) until a thickness of 100 micra was attained They were not stained The non

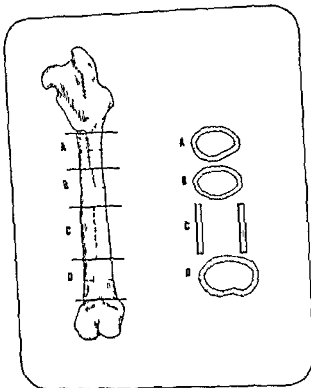


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mycin® Pfizer) 24 hours before sacrifice they were given 50 mg Alizarin Red S as 1 per cent sterile solution likewise by intravenous injection

For the animals used for macro-autoradiography, no exception was made to this rule in view of the possibility that Terramycin in the dose given could have a slight inhibitory effect of bone formation (Danckwardt Lilliestrom 1969 Rahn 1973) The two animals which survived 7 weeks after operation in each of the groups 1 through 5 were in addition given weekly one of the above mentioned newer fluorochromes as 3 per cent sterile solution (Rahn and Perren 1970 1971 1972) according to the plan shown in table 3

To study and photograph the sections we used a modified Zeiss Universal microscope with fluorescence equipment the vertical illuminator III RS and the attached camera LS Matic (Verhofstad and Schrijer 1975) Incident light excitation was used In relation to the light direction the sequence of the optical system used was as follows

Light source	high pressure mercury vapour lamp OSRAM HBO 200 W/4 heat absorption filter KG 1 red absorption filter BG 38
III RS (position 3) with (blue light excitation)	excitation interference blue filter KP 500 excitation interference blue filter KP 490 dichroitic interference mirror FT 510 barrier filter LP 520
or III RS (position 1) with (UV excitation)	UV permeable black glass UG 1 dichroitic interference mirror FT 420 UV barrier filter LP 418
Objective	Neofluar 6.3 0 2

For the colour reproductions presented in chapter 4 only position 3 of the vertical illuminator III RS was used the calcein blue which fluoresced only in position 1 is therefore not visible in these reproductions (table 3) The colour as reproduced on the film used (daylight film Kodak HS 23 DIN Ektachrom EH 135) visually corresponded with the colour of the microscope image Exposure times were 2 20 seconds.

3 12 *Macro-autoradiography*

Autoradiography shows the distribution of radioisotope labelled compounds over the various tissues Bone seeking radioisotopes are deposited in new and incompletely mineralized osteons and make it possible qualitatively to demonstrate distribution patterns in bone and such processes as growth and repair In combination with histological and fluorescence techniques it can be used to differentiate between processes of bone degeneration and bone regeneration

To put it simply the image produced by the radioactivity from a sample on a photographic emulsion is an autoradiogram On the developed film the sites where the radioactive element is localized appear as dark areas The Strontium ion used in this study so closely resembles

3 11 *Fluorochrome labelling*

Ordinary histological sections do no justice to the dynamics of such processes as growth, remodelling and regeneration of bone The use of vital staining agents which are bound to newly formed bone of any origin (Harris 1960, Harris et al 1964, Frost 1969) has added a new dimension to the study of these dynamic processes

In addition to the bestknown fluorochromes, the tetracyclines (Milch et al 1958, Harris 1960, Harris et al 1962), a need has arisen for other vital staining agents to be used in sequential labelling (Olerud and Lo renzi 1970, Rahn 1973) Alizarin Red S is perhaps too toxic (Harris 1960, Adkins 1965) Moreover, it has been reported to inhibit bone formation (Harris et al 1964), although others have refuted this (Vilmann 1969) Olerud and Lorenzi (1970) used it only immediately before sac rificing the test animal

Fluorochromes for experimental use which have a low systemic toxicity and no local effect on calcification, and at the same time give clearly defined colour differences are calcein (Suzuki and Mathews 1966), cal cein blue (Rahn and Perren 1970), xylenol orange (Rahn and Perren 1971) and Alizarin complexon (Rahn and Perren 1972)

During induction of anaesthesia all the animals used in the experiment received an intravenous injection of 50 mg/kg oxytetracycline (Terra

Table 3 Fluorochromes given for sequential labelling to the animals ob served over a period of 7 weeks

Fluorochrome	Dose per kg body weight	Mode of administration	Time of administration in weeks	Vertical illuminator III RS colour in position 1	position 3
Terramycin	50 mg	i v	0	white	yellow
Xylenol orange	90 mg	s c	1	pink	orange
Calcein blue	30 mg	s c	2	blue	—
Alizarin complexon	30 mg	s c	3	orange	deep red
Xylenol orange	90 mg	s c	4	pink	orange
Calcein	30 mg	s c	5	yellow	green
Alizarin complexon	30 mg	s c	6	orange	deep red
Alizarin Red S	50 mg (total)	i v	7 (24 hrs)	pink	red

3 13 *Disqualified animals*

A total of 19 animals (13 5 per cent) were disqualified from the ultimate experiment in which 141 animals were used Of these 19 animals 8 showed a femoral shaft fracture which in 7 instances was noticed only on postmortem radiographs or at examination of the histological sections In 3 animals the femurs proved to be insufficiently filled with acrylic cement Four animals all from group 4 (acrylic cement without catalyst) died during operation from histologically demonstrated fat embolism Two animals died shortly after intravenous injection of Alizarin Red S and two died from an intercurrent disease

3 14 *Summary*

In 7 x 18 rabbits femurs the medullary cavity was reamed a vent hole was drilled and the medullary contents were removed by suction In view of preliminary experience with a test group of 25 animals the vent hole was drilled as routine procedure

The procedure was continued by filling the medullary cavity with acrylic cement Dependent on the type of acrylic cement used the animals were divided into 7 groups

- only reaming and suction (group 1)
- insertion of a loose fitting intramedullary Palacos rod (group 2)
- filling of the medullary cavity with commercial acrylic cement (groups 3a and 3b)
- filling with acrylic cement without catalyst (groups 4a and 4b)
- filling with a modified acrylic cement Sulfix-6 with CMC gel (group 5)

The animals were sacrificed in pairs 1 2 3 4 5 6 and 7 weeks and 3 and 6 months after operation and the lower limbs were perfused with a Micropaque suspension The femurs were processed for radiological histological microangiographic and fluorescence microscopic examination The acrylic cement dissolved during processing of microscopic sections Six animals in which commercial acrylic cement had been implanted were followed up over periods of 9 12 and 24 months Of 10 animals from each group (1 2 3a 4a and 5) the femurs were used for macro-autoradiography after 1 or 4 weeks In 2 animals from each of the two groups 4a and 5 an autoradiogram was made after 4 months

the calcium ion that it is incorporated in bone crystals in an identical way Sr^{89} is a beta emitter with a half life of 51 days (McLean and Budy 1964)

The femurs of 10 rabbits (2 from each of the 5 principal groups) were micro autoradiographically studied 1 and 4 weeks after operation In 2 rabbits from groups 4a and 5, an autoradiogram was made after 4 months (table 4)

The survival of rabbits after injection of 80 μCi ^{89}Sr - SrCl in aqueous solution (Amersham) was always 24 hours Immediately after sacrificing the animals both femurs were removed and immersed for 10 minutes in a chilling mixture of dry ice and isopentane (–65° C to –75° C) Until further processing the bones were stored in a freezer at –18° C The bones were fixed by embedding them in a suspension of carboxymethylcellulose in water (5 per cent, medium viscosity, temperature 0° C) After embedding the bones the CMC suspension was frozen by chilling it to –15° C The CMC bloc was mounted on the movable stage of a microtome (Jung K) placed in a freezer (–15° C) Sections of 30 micra thickness were fixed on tape (Scotch 810 3AW) during cutting The strips of tape were then stretched on cardboard sheets Before a film (Agfa Gevaert Structurix D7) was placed on the fixed sections it was dried in a freezer (–18° C) during 48 hours The exposure time of the film was about 5 days

Table 4 The animals used for Sr^{89} macro autoradiography classified according to type of operation and period of observation

Rabbit no	Group	Type of operation	Survival in weeks
6463	1	RS*	1
6464	1	RS	4
6559	2	RS + Palacos rod	1
6481	2	RS + Palacos rod	4
6456	3a	RS + Palacos	1
6457	3a	RS + Palacos	4
6458	4a	RS + Palacos without catalyst	1
6459	4a	RS + Palacos without catalyst	4
6560	5	RS + Sulfix 6 with CMC gel	1
6479	5	RS + Sulfix 6 with CMC gel	4
6564	4a	RS + Palacos without catalyst	16
6563	5	RS + Sulfix 6 with CMC gel	16

* RS = reaming and suction of medullary cavity

will be discussed under the joint heading group 4 RS + PMMA without catalyst

The photomicrographs shown are representative of the group and observation period concerned

The photomicrographs of histological sections shown in this section depict haematoxylin-eosin (HE) stains The photomicrographs were made with the Leitz Orthomat on Scientia film 50-B-65 A green filter 546 nm was used in the exposures. The periosteum is always shown at the top of the photograph and details are viewed from the endosteal cortex side The legends to the figures mention in succession observation period group femur involved rabbit number segment number (A B C or D) and if necessary type of cement
Pa (= group 3A commercial Palacos)
Su (= group 3B commercial Sulfix-6)
Pa–C (= group 4A Palacos without catalyst)
Su–C (= group 4B Sulfix-6 without catalyst)

To summarize the groups to be discussed in the following sections will be referred to as

- group 1 reaming (R) and suction (S)
- group 2 RS + Palacos Rod
- group 3 RS + PMMA
- group 4 RS + PMMA without catalyst
- group 5 RS + modified Sulfix 6 with CMC gel

4 2 *Macroscopic findings*

Apart from a sligthly larger diameter as compared with the control bone the deep-frozen femurs showed no relevant changes Near the lateral femoral condyle at the site of the vent hole some callus tissue was usually found The distal cut surface was chosen in such a way that this callus tissue did not fall in the most distal sector (D) Once the femurs were cut into sections it was invariably found that the acrylic cement always filled the entire medullary cavity and was always fixed firmly to the bone regardless of the type of cement used This did not apply to the loose fitting rods in group 2 these however were encapsulated by regenerated bone marrow

4 3 *The normal histological features of the other femur used as control*

The normal histological features of the transverse section of the control femur show throughout the specimen osteons with vital osteocytes

CHAPTER 4

RESULTS

4 1 *Premises*

The typical reactions which occur in medullary cavity, cortex and periosteum following an intramedullary intervention have been described in detail in chapter 2 The same reproducible histological changes were observed also in our material, and need not be discussed in detail again in this chapter

In this discussion of results emphasis will be placed on a *comparison* of the changes observed in the various groups In all cases sections of the treated femur were also compared with those of the control femur Since no measurements were made the observations are only graphic and descriptive, and not suitable for statistical analysis

The histological sections provided the basis for the material studied All other investigations were complementary and helped to confirm the observations made on the histological material To avoid repetition the entire histological material including the fluorescence microscopic findings will be collectively discussed in sections 4 3 and 4 4 An exception will be made for the animals studied by sequential fluorochrome labelling during 7 weeks (sections 4 6 and 4 7)

In the Goldner stained sections the distribution and intensity of stained osteoid varied from section to section Sometimes the osteoid was stained in one animal but not in the other On the whole the data obtained provided too little constant information to warrant definite conclusions A detailed discussion would be detrimental to the surveyability of this documentation

It was also found that longitudinal sections C (fig 11) supplied no new information shortly after the start of the ultimate experiment therefore section C was used for making transverse sections

Since no essential differences in the reaction pattern of cortex medullary cavity and periosteum were observed in the material from groups 3A (commercial acrylic cement Palacos) and 3B (commercial acrylic cement Sulfix 6), the two groups will be discussed under the joint heading group 3 RS + PMMA The same applies to groups 4A and 4B which

will be discussed under the joint heading group 4 RS + PMMA without catalyst

The photomicrographs shown are representative of the group and observation period concerned

The photomicrographs of histological sections shown in this section depict haematoxylin-eosin (HE) stains The photomicrographs were made with the Leitz Orthomat on Scientia film 50-B-65 A green filter 546 nm was used in the exposures. The periosteum is always shown at the top of the photograph and details are viewed from the endosteal cortex side The legends to the figures mention in succession observation period group femur involved, rabbit number segment number (A B C or D) and if necessary type of cement
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To summarize the groups to be discussed in the following sections will be referred to as

group 1 reaming (R) and suction (S)
group 2 RS + Palacos Rod
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Apart from a sligthly larger diameter as compared with the control bone the deep frozen femurs showed no relevant changes Near the lateral femoral condyle at the site of the vent hole some callus tissue was usually found The distal cut surface was chosen in such a way that this callus tissue did not fall in the most distal sector (D) Once the femurs were cut into sections it was invariably found that the acrylic cement always filled the entire medullary cavity and was always fixed firmly to the bone regardless of the type of cement used This did not apply to the loose fitting rods in group 2 these however were encapsulated by regenerated bone marrow

4 3 *The normal histological features of the other femur used as control*

The normal histological features of the transverse section of the control femur show throughout the specimen osteons with vital osteocytes

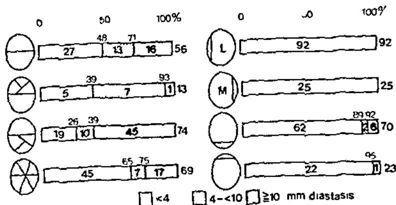


Fig 6 Separation of the fragments in various types of patellar fracture

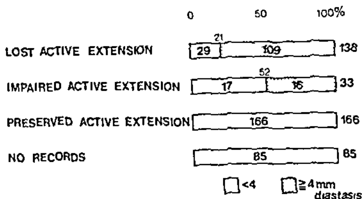


Fig 7 Function of the quadriceps apparatus with respect to separation of the fragments in 416 patients with patellar fractures

Of the patients who were considered to suffer from loss of active function of the quadriceps apparatus 109 (79%) had a separation between the fracture parts of at least 4 mm (Fig 7) The diastasis did not exceed 5 mm in any of the 16 patients who had impaired active extension of the knee

A step in the articular surface of the patella of 3 mm or more in concomitant diastasis less than 4 mm was found in six patients (Fig 8) Five of these had preserved active extension of the knee while one had loss of active extension

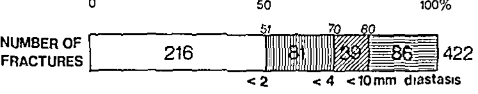


Fig 4 Distribution of 422 patellar fractures with respect to separation of the fragments

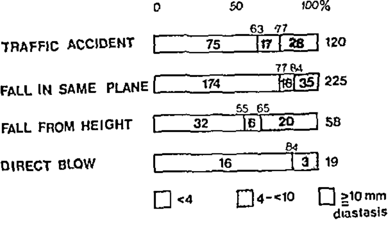


Fig 5 Distribution of 422 patellar fractures with regard to various modes of injury and *resulting separation of the fragments*

than 10 mm and as considerable if the separation between the fragments was at least 10 mm There was no dislocation in 216 fractures (51%) Fig 4 In a further 19 per cent the diastasis was less than 4 mm In 125 fractures (30%) the diastasis was 4 mm or more Of these 86 fractures (20%) had a diastasis of at least 10 mm

Considerable diastasis was observed in 35 per cent of the fractures caused by fall from height (Fig 5) The diastasis was often slight in falling in the *same plane*

Transverse fractures with a split lower pole were often dislocated In 61 per cent there was a separation between the *fragments of at least 10 mm* (Fig 6) Considerable diastasis was established also in transverse fractures with two large fragments (29%) and in comminuted fractures (25%) Only in exceptional cases was there a considerable diastasis in transverse fractures with a split upper pole as well as in apical and basal fractures In longitudinal fractures the diastasis did not in any case exceed 4 mm

(68%) and operative treatment on 135 fractures in 134 patients (32%) The distribution of non surgical and surgical treatment with regard to various age groups among males and females is tabulated in Fig 9

The methods used in non surgical treatment are mentioned in Table 11

Non surgical treatment as a rule included immobilization in plaster reaching from the malleoli to the inguen In some cases the haematoma in the knee was first punctured An elastic adhesive bandage was regarded as adequate in some cases whilst in others no treatment was considered necessary

Of the 282 non surgically treated patients 214 were ambulant and 68 were treated as in patients The median period of hospitalization was six days

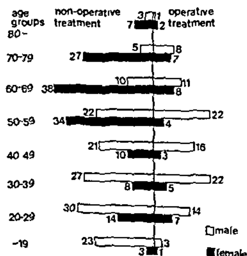


Fig 9 Non operative and operative treatment of 416 males and females of different ages with patellar fracture

Table 11 Non-operative treatment of 287 fractures of the patella

Treatment	(fracture type 1)	(fracture type 2)	(fracture type 3)	(fracture type 4)	L	M	(fracture type 7)	(fracture type 8)	Total
Plaster cast	0	5	14	38	60	10	44	11	20-
Elast adhesive bandage		1	3	5		12	9	8	6
No treatment	3			2	-	1	9	1	3
Total	5/56	6/13	17/ 4	45/69	89/9	?3/ 5	6?/ 0	?0/ 3	287/4

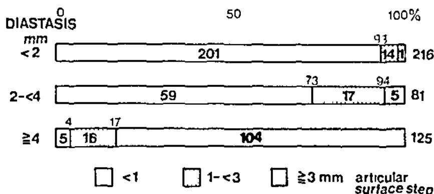


Fig 8 Relation between diastasis and articular surface step in 422 patellar fractures

Treatment

On the same day of the trauma 306 patients (74%) came for treatment to the hospital and 83 (20%) within a week The remaining 27 (6%) did not come to the hospital until one week or more had elapsed 202 (48%) were treated as in patients

The treatment was given at El manska sjukhuset (1/1–15/10 1959) at the two Clinics of Orthopaedic Surgery and at the Surgical Clinics

The treatment was selected according to the following principles Non operative methods were considered applicable if the difference in level between the fragments was less than 3 mm if the patient could lift his leg with his knee extended and/or if the diastasis between the fracture parts was less than 4 mm If there was loss of active extension despite the diastasis being less than 4 mm the patients were hospitalized If the extension capability was restored—possibly after puncture of the joint—the patients were not subjected to surgery In all the other cases surgery was indicated

Owing to loss of active extension eleven patients were surgically treated despite the diastasis between the fragments being less than 4 mm In four cases it was stated that the lateral expansions were uninjured and in two that they were torn In five cases the statements were unreliable

Five patients were surgically treated despite there not being any loss of active extension and despite the diastasis between the fragments being less than 4 mm In these cases the lateral expansions were uninjured

Six patients were not operated on despite the diastasis between the fracture parts being 4 mm or more Of these five had impaired active function of extension and one patient had sustained polio and wore a lower extremity support

Non operative treatment was performed on 287 fractures in 282 patients

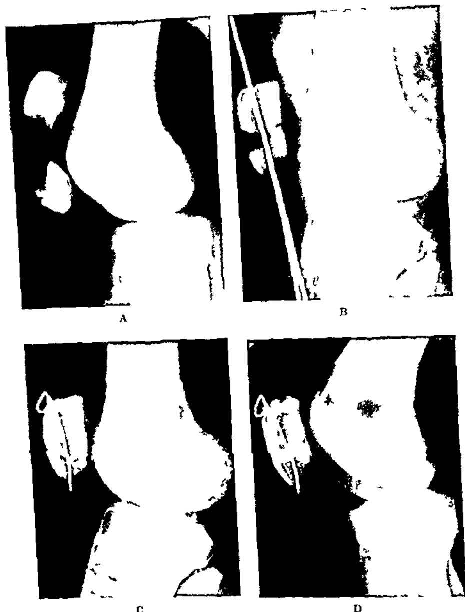


Fig 11 See text on page 36

The main principle was to restore the normal anatomy of the patella The most common method of operation was osteosynthesis with a stainless steel wire inserted through two longitudinally drilled holes In principle the operation was performed as follows The operation was made in a bloodless field

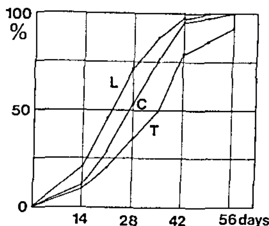


Fig 10 Cumulative distribution graphs showing period of immobilization in plaster cast in various non operatively treated types of patellar fracture (L=longitudinal fractures C=comminuted fractures T=all types of transverse fractures)

Table 12 Surgical methods of treatment for various types of patellar fracture Other methods for osteosynthesis were metal pin (one case) metal wire through cross drill d holes (two cases) suture with silk linen or catgut (five cases)

Treatment					L	M			Total
Osteosynthesis									
longitudinally drilled holes	21	3	30	13			2		69
transversally drilled holes	2		1					1	4
encircling wire	5	1	3	3					12
other methods	*1*	*1*	*2*		*3*		*1*		8
Partial patellectomy		2	21	3		2	5	1	34
Total patellectomy	1			5					6
Exploration	1							1	2
Total	31/[illegible]6	7/13	57/74	24/69	3/92	2/25	8/[illegible]0	3/23	13[illegible]/4[illegible]

The approximate median period of immobilization in plaster after non surgical treatment was four weeks and shorter for longitudinal fractures than for transverse and comminuted (Fig 10)

When there was an indication for surgery the operation was performed on the same day or on that following The methods of operation employed are given in Table 12

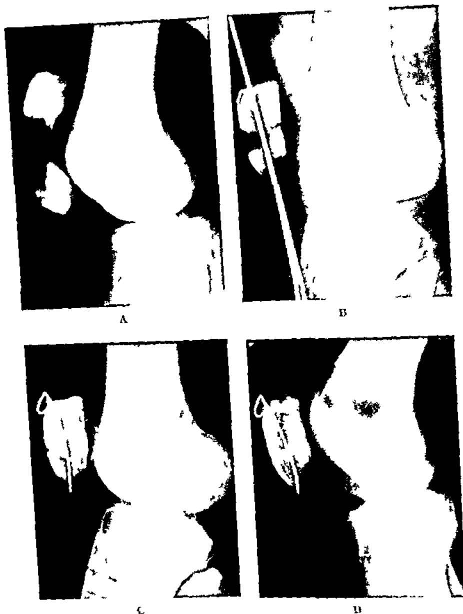


Fig 11 See text on page 3?

The main principle was to restore the normal anatomy of the patella The most common method of operation was osteosynthesis with a stainless steel wire inserted through two longitudinally drilled holes In principle the opera tion was performed as follows The operation was made in a bloodless field





Fig 11 Transverse fracture of the patella with two large fragments (A) treated by osteosynthesis with metal wire through longitudinally drilled holes (B–C) B shows two Kirschner wires piercing the fragments (The result eight years later (D–F) was excellent)

After mal ing a medial parapatellar incision the prepatellar bursa was extirpated The joint cavity was syringed carefully with physiological saline solution The tear of the lateral expansions was identified After removing any small fragments the fracture parts were fastened together by means of bone clamps Two Kirschner wires with a needle s eye were drilled parallelly into the proximal fragment starting at the basis (Fig 11) As it was often impossible to drill through both fragments at the same time the wires were drilled across the line of the fracture far enough to allow distinct impressions to be made in the distal fragment *This indicated where another pair of Kirschner wires* could be inserted A 0 9 mm stainless steel wire was attached to the Kirschner wires and drawn bacl to the basis where it was tightened with a wire twister Then the wire ends were recessed into a channel made with an awl in the basis of the patella Restoration of the articular surface was very much facilitated by inserting a finger into the joint and at the same time hyperextending the knee thus permitting the articular surface to be palpated (Moberg 1944) After completing the osteosynthesis the tear of the lateral expansions was repaired with catgut or silk

Partial patellectomy retaining one large fragment was the most important alternative to osteosynthesis and was mainly used in transverse fracture with a split lower pole (Fig 12)



A



B



C

Fig 1 Transverse fracture of the patella with a split lower pole (A) treated by partial patellectomy (B) (Th result ten years late (C) was excell nt)

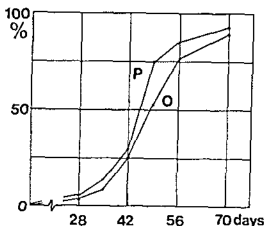


Fig 13 Cumulative distribution graphs showing duration of immobilization in plaster cast in patellar fractures treated by osteosynthesis and partial patellectomy (P=partial patellectomy O=osteosynthesis)

Only in exceptional cases—in open fractures—was the patella completely excised

In open injuries the fracture was surgically treated in 19 out of 23 cases The operation was performed at the acute stage with one exception In nine cases osteosynthesis was carried out in five the patella was partly excised and in another five total patellectomy was performed

After the operation the leg was immobilized in a plaster cast reaching from the malleoli to the inguen and the knee was fixed in a flexed position of 5–10 degrees As a rule there was no drainage Generally the patient remained in bed for 3–4 days after the operation with the leg elevated Isometric exercise of the quadriceps muscle was begun on the day after the operation After a few days leg raising exercises were instituted Crutches were used after the mobilization as protecting support but weight bearing was allowed

The median period of hospitalization in operative treatment was twelve days

The median period of immobilization in plaster cast was 6 5 weeks (Fig 13) This period did not vary with the methods of operation

When the plaster cast had been removed the patient was given verbal instructions about extension and flexion exercises A physiotherapist supervised when necessary

Complications

No patient died owing to fracture of the patella There were complications in 19 patients (5%) Table 13

Four patients sustained refracture after osteosynthesis. In three of these cases the operation had been performed with a stainless steel wire inserted through longitudinally drilled holes. The group "Other Complications" included five patients. Two of these got paralysis of the peronaeus which became permanent in one. Suture migration was found in two patients. Finally in one patient there was a lengthening of the quadriceps tendon after total excision of the patella; on re-operation shortening of the tendon was performed.

In none of the cases severe infection of the joint set in. No cases of deep thrombosis nor thrombo-embolism were diagnosed.

Re-operations

22 patients (5%) were re-operated on (Table 14).

Release of adhesions was performed in eleven cases. If the mobility was considerably impaired the patella was mobilized during complete relaxation of the muscles. In no case was this manipulation carried out earlier than two months after the trauma. A sharp hook was inserted percutaneously at the basis

Table 13. Complications in 19 out of 416 patients with fracture of the patella

Treatment	Complications: Wound infection	Refracture	Other	Total
Non-operative		2	1	3
Osteosynthesis	5	4	1	10
Partial patellectomy	1		1	2
Total patellectomy	2		2	4
Total	8	6	5	19

Table 14. Re-operations in 22 out of 416 patients with fracture of the patella

Primary treatment	Re-operations: Osteosynthesis	Total excision	Removal of metal wire	Release of adhesions	Other	Total
Non-operative		1		3	1	5
Osteosynthesis	2		4	6	2	14
Partial patellectomy				2		
Total patellectomy					1	1
Total	2	1	4	11	4	

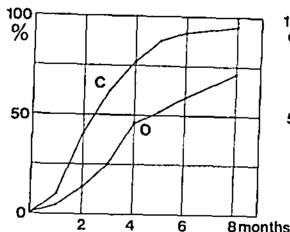


Fig 14

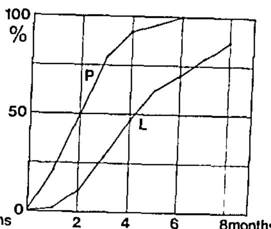


Fig 15

Fig 14 Cumulative distribution graphs showing period of sick leave after closed and open fracture of the patella Concomitant injuries are included (C=closed *fracture* O=open fracture)

Fig 15 Cumulative distribution graphs showing period of sick leave in preserved and lost function of the quadriceps in fracture of the patella Open fractures and concomitant *injuries are excluded* (P=preserved quadriceps function L=lost quadriceps function)

of the patella lifting the patella slightly By pressing the thumb against the patella it was carefully worked loose Small movements from side to side were also brought about By this careful manipulation it was possible to avoid breaking forces of the fracture line or tension of the row of sutures The *mobilization had in all cases the intended effect and involved no complications*

Four patients were included in the group of Other Re operations the one mentioned above on whom a shortening of the quadriceps tendon was performed two in whom sutural granulomas were extirpated and one on whom an explorative arthrotomy was done in a late phase because of diffuse joint *pain In this case there was a slight defect corresponding to the fracture*

Sick leave

Of 416 patients 306 received sickness benefit The period of sick leave also depended on factors other than the fracture There was no difference between *the sexes nor between the occupations in the length of time of sick leave* After open fracture the median period of sick leave was twice as long as that after closed (Fig 14) If the extensor function was preserved *indicating a minor injury* to the lateral expansions half the number of patients was discharged after two months (Fig 15) If there was loss of active extension four months elapsed before half the number of patients had recovered

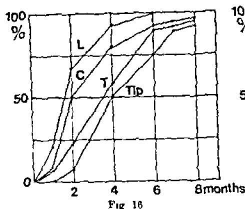


Fig 16

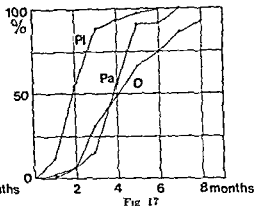


Fig 17

Fig 16 Cumulative distribution graphs showing period of sick leave for different types of patellar fracture Open fractures and concomitant injuries are excluded (L=longitudinal lateral fractures C=comminuted fractures T=transverse fractures with two large fragments Tlp=transverse fractures with a split lower pole)

Fig 17 Cumulative distribution graphs showing period of sick leave with different methods of treatment in patellar fractures Open fractures and concomitant injuries are excluded (Pl plaster cast—non-operative treatment Pa=partial patellectomy O=osteosynthesis)

Longitudinal lateral fracture (as well as longitudinal medial apical and basal fracture) resulted in shorter periods of sick leave as compared with other types of fracture (Fig 16)

Of the patients with a longitudinal lateral fracture 68 per cent were discharged after two months as restored but of those who had a transverse fracture with two large fragments only 22 per cent

The median period of sick leave for patients with a fracture not requiring surgical treatment was half of that required for patients with a fracture treated surgically (Fig 17)

After four months 91 per cent of the non surgically treated patients immobilized in a plaster cast had returned to work but only 49 per cent of those on which osteosynthesis had been performed The median period of sick leave was *slightly* shorter after partial patellectomy than after osteosynthesis

Certificate of disablement

After the treatment was terminated 19 patients received a *certificate of disablement* Two of these had concomitant injuries *Of the remaining 17 patient five were granted lifelong compensation equivalent to a reduced capacity for work by 10–25 per cent Temporary compensation was granted to two patients* The reduced capacity for work in the remaining ten cases was not found to exceed 10 per cent

CHAPTER IV

FOLLOW—UP STUDY

Case series

The follow up study was carried out during the period 1970–1971 The time of observation varied from 5 to 12 years The mean time of observation was 8 9 years The follow up study included 321 subjects (327 fractures) constituting 91 per cent of those alive at the time of the investigation 63 subjects had died 32 subjects were impossible to reach for various reasons Of the 321 subjects 247 were thoroughly *examined according to the method mentioned* below A further 25 subjects most of whom were elderly were examined in nursing homes homes for the aged or in their own homes but were not *radiographically examined The remaining 49 answered questionnaires but* were not examined Of these 49 subjects 21 were asked to come for examination more than four times but refused 22 lived more than 50 km from the hospital and a further six had died before the clinical investigation was terminated

From the time of injury to the time of the follow up 16 subjects sustained diseases and injuries in the same extremity earlier injured Of these eleven sustained a fracture of the femoral neck two other kinds of fracture and three injury of the meniscus Four subjects were struck by diseases and injuries in the other leg Two of these sustained a fracture of the femoral neck one a fracture of the ankle joint and one injury of the meniscus These 20 subjects are included in the series

One subject later sustained a new fracture of the patella of the same leg and was subjected to total patellectomy He was excluded from the series Two subjects later fractured the patella of the other leg These two latter fractures were not treated surgically The second fracture caused no discomfort They are included in the series but the other knee injured later was regarded as uninjured

When checking the series it was found that of the six subjects who had sustained bilateral fractures of the patella four had one slightly and one severely injured knee the latter of which only had been surgically treated one subject was non surgically treated bilaterally and the remaining was operated on both sides The condition of the latter subject at the follow up

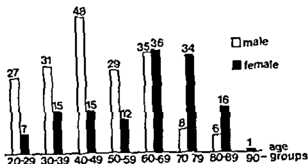


Fig 18 Distribution of age and sex among 320 subjects with fracture of the patella at the follow up study

was affected by the sequelae of a cerebral insult One knee of the two latter subjects and the slightly injured knee of the other four will in the following be regarded as uninjured The percentage of the poor results in the final report will not be affected by this exclusion

In the continued report of subjective symptoms the series includes 320 subjects The objective and radiographic findings are based on 271 and 246 subjects respectively

The distribution of the patients followed up with regard to age and sex is indicated in Fig 18

The mean age of the subjects followed up was 53 years i e for 184 males 47 years and for 136 females 61 years The youngest subject was 21 years and the oldest 96 years of age

The distribution of non operative and operative treatment among various age groups of males and females in the follow up study is stated in Fig 19

Methods of treatment of various types of fracture are specified in Table 15

Methods

A questionnaire was sent to the subjects in which they were asked to state the following symptoms and active function as conceived before and after the injury pain swelling stiffness unsteadiness limping use of stick capability for walks mounting stairs running and sports Furthermore they mentioned further sick leave because of the same injury change of occupation life annuity and whether they believed that the injury had caused permanent disability

At the clinical examination between six and twelve months later the questionnaire was verbally discussed The congruence of the verbal and written answers was satisfactory and consequently it was believed that the subjects whose condition was assessed merely on the basis of the questionnaire had given an adequate account of their condition

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When checking the series it was found that of the six subjects who had sustained bilateral fractures of the patella four had one slightly and one severely injured knee the latter of which only had been surgically treated one subject was non surgically treated bilaterally and the remaining was operated on both sides The condition of the latter subject at the follow up

The nature and degree of pain and the subjectively experienced impairment of function was assessed on the basis of verbal and/or written questioning Pain and ache were classified according to the following

1 Temporary ache e g with atmospheric changes or in kneeling posture
2 Ache when starting to walk or in connection with a lengthy position e g in a squatting posture
3 Ache in connection with exertions
4 Ache caused by all activities
5 Pain at rest

In analyzing the impairment of function consideration was taken to the age of the subject An age limit of 60 years was selected and the functions included were scored (Table 16)

At the clinical examination walking on a level surface as well as the capability of mounting and descending stairs were assessed Extension defect and range of mobility of the knee joints were measured with an angle gauge The maximal circumference of the calf the circumference on a level with the patella and the circumference of the thigh 15 cm proximally to the medial interarticular space were measured on both legs

Methods of measuring the extension force of the knee have been elaborated by Clarke *et al* (19[illegible]0) He suggests a sitting posture with the knee joint

Table 16 Estimation of subjectively experienced impairment of function

Subjectively experienced impairment of function	Age in Years ≧60	<60
Feeling of unsteadiness or weakness	1	[illegible]
Limping — following exertions	0	1
— always	1	2
Support — only outdoors	1	1
— always	[illegible]	2
Walking distance — impaired (<5 km)	2	2
— severely impaired (<1 km)	4	4
Walking up and down stairs — slowly but with alternating steps	1	1
— mounting stairs with healthy leg first and descending stairs with injured leg first	2	-
Running — impaired	0	2
Sport — impaired	0	[illegible]
Maximal score	10	16

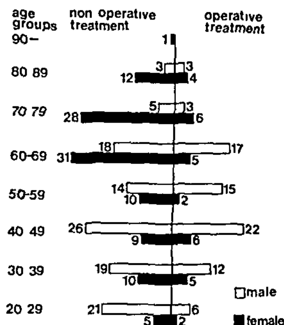


Fig 19 Non operative and operative treatment of patellar fracture in males and females of different ages among 3?0 subjects in the follow up examination

Table 15 Methods of treatment for different types of patellar fracture in the follow up study

Treatment					L	M			Total
Non operative treatment	*18*	*5*	*13*	*29*	*63*	*[illegible]0*	*51*	*13*	[illegible]12/287
Osteosynthesis									
longitudinally drilled									
holes	17	2	[illegible]3	10			2		54/69
transversally drilled									
holes	2								[illegible]/4
encircling wire	3	1	3	2					9/12
other methods	1	1	[illegible]		3		1		8/8
Partial patellectomy		2	16	3		2	4	1	[illegible]8/34
Total patellectomy	1			4					[illegible]/6
Exploration	1							1	[illegible]/[illegible]
Total	43/56	11/13	57/74	48/69	66/9[illegible]	2[illegible]/[illegible]	58/70	1[illegible]/23	3 0/4

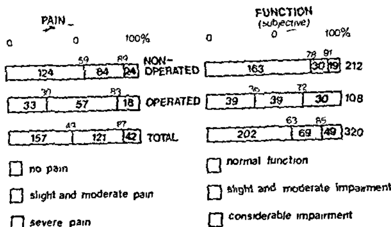


Fig. 20. Subjective symptoms after non-operative and operative treatment of fracture of the patella. (The figures refer to percentage and number of subjects.)

Results

Subjective Symptoms (320 subjects)

When the treatment was ended 78 subjects (24%) did not consider themselves to be fully recovered. At a later date 44 (14%) came for consultation because of discomfort which could depend upon the injury. An operation was performed on eight of these. At the time of the questioning 225 (70%) were satisfied.

The pain in the injured knee was considered as slight if it occurred in connection with kneeling or atmospheric changes, as moderate when starting to walk and as the result of a lengthy squatting posture or during exertions. The pain was regarded as severe if it persisted at rest and/or in all activities. It was found that 157 subjects (49%) had no pain and 63 (20%) had slight pain. Moderate pain was noted in 58 (18%) and severe in 42 (13%) subjects.

The subjectively experienced impairment of function was considered slight if the corresponding score did not exceed 2 points. The impairment of function was moderate if the score exceeded 2 but not 4 and 6 points respectively. If the score was higher the impairment of function was classified as considerable. No abnormality of the function was stated by 202 subjects (63%). Slight impairment of function was found in 51 (16%), moderate in 18 (6%) and considerable in 49 (15%) subjects.

Subjective symptoms after non-surgical and surgical treatment are indicated in Fig. 20.

None of the 49 subjects who merely answered the questionnaires had severe

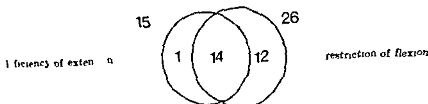
flexed through 45 degrees Tornvall (1963) and Backlund & Nordgren (1968) measured the force with the subject in a sitting posture and the knee joint flexed through 90 degrees The mean value of the subjects aged 20–28 years was in the Tornvall series 50 kgf on the right and 47 kgf on the left side In medical students of the same age Backlund & Nordgren found 65 kgf on the right and 64 kgf on the left side

The force of the extensor muscles was measured in a special chair designed by Hook & Tornvall (1969) and equipped with a strain gauge dynamometer for measuring isometric power muscles The knee was flexed through 90 degrees The maximal force was recorded—often after several attempts the last value obtained being lower than the highest—and a percentage of the reduction of force was calculated on the force of the uninjured leg Measurements of the force of the knee extension was made with the assistance of Ewa Landegren, laboratory assistant Dept of Medical Rehabilitation II Sahlgren s hospital In cases when the subjects were examined elsewhere than in the hospital Zadig s dynamometer was employed (Zadig 1963)

Enlargement of the patella and its mobility was recorded as well as tenderness across the patella and crepitations in the knee joint

Radiographs were taken of both knee joints including frontal lateral and axial projections on the injured side, two oblique projections were taken as well For loading the patellofemoral joint while the axial projection was taken the subject was standing with the patella to be examined resting against a support mounted on a special examining stand and with the knee in a semi flexed position (Ahlback 1968) Other exposures were taken with the subject in a recumbent position (Ass Professor Sven Scheller planned the radiographic examination which was carried out by assistants at The Roentgen Department I Sahlgren s hospital Recording and assessment of the radiographic findings were performed by the author in conjunction with Ass Professor Scheller)

Appraisal of the consolidation of the fracture fibrous union and pseudarthrosis was included in the radiographic analysis Cerclage breakage was recorded as well as articular surface steps enlargement of the patella calcium bodies and bone resembling tissue in the surrounding area and formation and development of osteoarthrosis For the estimation of osteoarthrosis the most important factors were changes of the structure—deformation of articular surfaces presence of cysts and subchondral sclerosis—and a reduced joint space The presence of osteophytes was not sufficient evidence for osteoarthrosis to be diagnosed A source of error could exist as the femorotibial joint—as opposed to the patellofemoral joint—was not examined during weight bearing of the knee Osteoarthrosis was recorded and classified according to Kellgren & Lawrence (1957) and Kellgren (1963)



F g 7 Restrict d rang of mol lity in 27 subjects after patellar fracture

could be measured The range of mobility of the injured knee was normal in 244 subjects (90%) Restricted range of mobility was found in 27 subjects (10 %) Deficiency of extension was recorded in 15 subjects (6%) Eight of these had moderate and seven considerable deficiency The flexion was restricted in 26 subjects (10%) Out of these 14 had moderate and 12 considerable restriction Both the deficiency of extension and the bending capacity to a flexed po ition of less than 120 degrees were recorded in 14 subjects (Fig 23)

Out of 27 subjects with restricted range of mobility 21 (78%) were older than 60 years of age Operation had been performed on 16 subjects (60%) The median period of immobilization in plaster 6 5 weeks was exceeded in 6 subjects (38 %) who were surgically treated

The circumference of the thighs was regarded as equal if the difference in the values mea ured was nil or less than 1 cm If the circumference of the thigh was reduced by at lea t 1 cm atrophy of the quadriceps musculature was as umed Atrophy was assessed as moderate if the reduction was less than 2 cm and con iderable if the reduction was at least 2 cm The circumference of the thighs was equal in 185 subjects (68%) Atrophy of the injured side was moderate in 38 (14%) and con iderable in 27 subjects (10%) The circumference of the thigh of the injured side was increased in 21 subjects (8%)

The exten ion force of the knees was regarded as equal if the same value including a decrease or increase of 10 per cent was obtained for both sides The exten ion force of the injured side was con idered to be reduced if the reduction was more than 10 per cent and to be augmented if the increase was more than 10 per cent The reduction of force was classified as mod rate if the reduction was less than 30 per cent and con iderable if the reduction was at lea t 30 per cent Equal force was mea ured in 150 subjects (55%) Moderate reduction of force was noted in 64 (24%) and con iderable in 3 subjects (13%) In 22 subjects (8) the force of the extensor apparatus of the injured knee was increased

Only in exceptional cases did the force of the extensors exceed 80 kg The force of the extensors in the healthy knee varied with age and sex as shown

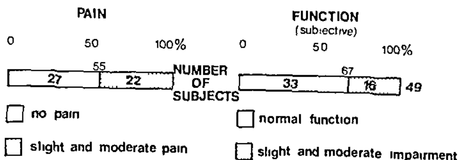


Fig 21 Subjective symptoms of 49 subjects who merely filled up the questionnaires

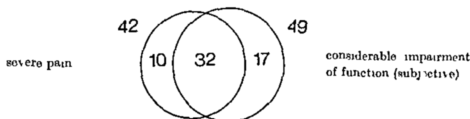


Fig 22 Severe pain and/or subjectively experienced considerable impairment of function in 59 subjects after fracture of the patella

pain or subjectively experienced considerable impairment of function (Fig 21)

Both severe pain and subjectively experienced considerable impairment of function were stated by 32 subjects (Fig 22)

The occupation of 243 subjects (76%) was the same or similar to that before the injury The conditions of living of 61 subjects (19%) irrespective of the injury had changed Most of these had received their old age pension 16 subjects (5%) had received a disablement pension or had changed over to lighter work owing to the injury Of these eight had temporary or lifelong compensation

Objective Signs (271 subjects)

The range of mobility of the injured knee was considered as normal if there was no deficiency of extension and if the knee could be flexed to at least 120 degrees It was considered as restricted if there was deficiency of extension and/or the bending capacity to a flexed position of less than 120 degrees could be measured The restriction was regarded as moderate if the deficiency of extension was less than or 10 degrees and/or the bending capacity could be measured to a flexed position of less than 120 degrees but more than 90 degrees It was regarded as considerable if the deficiency of extension exceeded 10 degrees and/or the bending capacity to a flexed position of 90 degrees or less

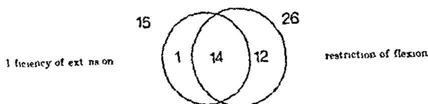


Fig 23 Restricted range of mobility in 27 subjects after patellar fracture

could be measured The range of mobility of the injured knee was normal in 244 subjects (90%) Restricted range of mobility was found in 27 subjects (10%) Deficiency of extension was recorded in 15 subjects (6%) Eight of these had moderate and seven considerable deficiency The flexion was restricted in 26 subjects (10%) Out of these 14 had moderate and 12 considerable restriction Both the deficiency of extension and the bending capacity to a flexed position of less than 120 degrees were recorded in 14 subjects (Fig 23)

Out of 27 subjects with restricted range of mobility, 21 (78%) were older than 60 years of age Operation had been performed on 16 subjects (60%) The median period of immobilization in plaster 6 5 weeks was exceeded in 6 subjects (38%) who were surgically treated

The circumference of the thighs was regarded as equal if the difference in the values measured was nil or less than 1 cm If the circumference of the thigh was reduced by at least 1 cm atrophy of the quadriceps musculature was assumed Atrophy was assessed as moderate if the reduction was less than 2 cm and considerable if the reduction was at least 2 cm The circumference of the thighs was equal in 185 subjects (68%) Atrophy of the injured side was moderate in 38 (14%) and considerable in 27 subjects (10%) The circumference of the thigh of the injured side was increased in 21 subjects (8%)

The extension force of the knees was regarded as equal if the same value including a decrease or increase of 10 per cent was obtained for both sides The extension force of the injured side was considered to be reduced if the reduction was more than 10 per cent and to be augmented if the increase was more than 10 per cent The reduction of force was classified as moderate if the reduction was less than 30 per cent and considerable if the reduction was at least 30 per cent Equal force was measured in 150 subjects (55%) Moderate reduction of force was noted in 64 (24%) and considerable in 35 subjects (13%) In 22 subjects (8%) the force of the extensor apparatus of the injured knee was increased

Only in exceptional cases did the force of the extensors exceed 80 kg The force of the extensors in the healthy knee varied with age and sex as shown

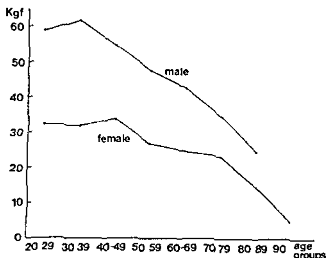


Fig 24 Mean values of the force of the extensors in the knee of the uninjured side of 271 subjects

in Fig 24, in which the mean values are given for males and females in the various age groups

The rate of considerable reduction of extension force was the same for subjects younger and older than 60 years of age Considerable reduction of force was found in 20 (23%) of 88 subjects whose injury caused loss of active extension and in 6 (5%) of 114 subjects whose capability of extension was preserved despite the injury Considerable reduction of force was found in 19 (23%) subjects with the fragments of fracture dislocated at least 4 mm and in 16 (8%) with a diastasis less than 4 mm ($p<0\ 01$) Considerable reduction of force was found in 23 (26%) operated and 12 (7%) non operated subjects ($p<0\ 01$) Out of the 23 subjects operated upon 16 were subjected to osteosynthesis three to partial patellectomy and four to total patellectomy (26% 13% and 100% of the respective follow up series)

With an equally large circumference of the thighs great deviations in the extension force could be obtained When the circumference of both thighs was the same the force measured in one subject could be increased by 20 per cent in the injured leg and in another reduced by 60 per cent The extension force was reduced in 77 (42%) of the 185 subjects in whom no atrophy was diagnosed On the other hand there was no subject who had considerable atrophy and increased extension force in the same leg

The extension force was reduced in 25 (93%) of the 27 subjects who had restricted range of mobility of the injured knee



A



B

Fig 5 Longitudinal lateral fracture of the patella (A) treated with immobilization in plaster (B) shows fibrous union six years later (The late result was good)

Radiographic Findings (246 subjects)

2, subjects were clinically but not radiographically examined 19 were older than 60 years 22 were not inconvenienced by the knee injury whilst three maintained that they had persisting disability owing to the injury Four elderly subjects who were free from symptoms had restricted range of mobility of the injured knee joint The circumference of the thighs was equal in all the 2, subjects Six subjects three of whom were free from symptoms had reduced extension force of the injured knee

Union of the fracture fibrous union pseudarthrosis articular surface steps and enlargement of the patella could be established by radiographic evidence in all the subjects except four on whom total patellectomy had been performed In 221 subjects (91%) the fracture had united

Fibrous union was established in 15 subjects (6%) Fig 25 Out of these twelve had a longitudinal lateral fracture (Table 17) All 15 subjects were treated non operatively

Pseudarthrosis was established in 6 subjects (3%) The fact that they had pseudarthrosis was unknown to all of them Four were treated non operatively and two operatively (Table 17)

Table 17 Distribution of various types of fracture among 1? radiographically examined subjects having had patellar fractures ending in fibrous union pseudarthrosis and articular surface steps The figures in brackets indicate operatively treated cases

Radiograph findings					L	M			Total
Fibrous union	1			2	1				15 (6%)
Pseudarthrosis		1		1 (1)	1	- (1)		1	6 (3%)
Articular surface step ≥1 mm	7 (6)	4 (1)	10 (9)	6 ( )	-	1	1	4	40 (1)



A



B



C



D

Fig 26 Comminuted fracture of the patella (A–B) treated non operatively Six years later the patella was enlarged (C) compared with the opposite side (D) (The late result was excellent)

Out of the radiographically examined subjects 51 were operatively treated by application of a metal wire In 46 cases the wire was intact but in five it had broken in one or two places

A step in the articular surface of the patella of 1 mm or more was established in 40 subjects (17%) Table 17 Out of these 22 were not and 18 were subjected to surgery *In 15 cases osteosynthesis was performed with a stainless steel wire* inserted through longitudinally drilled holes

Enlargement of the patella was considered to exist if an increase of width of at least ½ cm could be measured on the radiograph (Fig 26) 39 (17%) had



Fig. 27 Transverse fracture of the patella with a split lower pole (A) treated with osteosynthesis with a metal wire through longitudinally drilled holes. B and C seven years later show bone resembling tissue in the surroundings of the patella and articular surface step. (The late result was poor.)

enlargement of the patella of the injured side. Out of these 22 were non operatively and 17 operatively treated constituting 13 and 21 per cent of the respective follow up series. Enlargement of the patella was established after both osteosynthesis and partial excision.

Sometimes calcium bodies in the surroundings of the patella were visible on the radiograph and pretty frequently bone resembling tissue could be seen in the patellar ligament and the quadriceps tendon (Fig. 27). These kinds



A



B



C



D

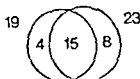
Fig 26 Comminuted fracture of the patella (A B) treated non operatively Six years later the patella was enlarged (C) compared with the opposite side (D) (The late result was excellent)

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osteoarthrosis of the patellofemoral joint

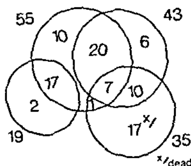


osteoarthrosis of the femorotibial joint

Fig 9 Osteoarthrosis of the uninjured knee of 27 subjects after patellar fracture of the opposite side

osteoarthrosis of the patellofemoral joint of the injured knee

osteoarthrosis of the patellofemoral joint of the opposite side



osteoarthrosis of the femorotibial joint of the injured knee

osteoarthrosis of the injured knee at the time of injury

Fig 30 Osteoarthrosis of the injured knee as well as of the patellofemoral joint of the opposite side at the follow up examination and osteoarthrosis of the injured knee at the time of injury

femoral and and femorotibial joints of the same knee and furthermore develop bilaterally (Ahlbäck 1968) and as osteoarthrosis had been diagnosed in the primary series a diagram could be traced (Fig 30) showing the cases in which it could be assumed that the osteoarthrotic changes in the patellofemoral joint of the injured side had developed as a result of the injury There remained ten cases as stated in the diagram

However when patellofemoral osteoarthrosis was observed on the injured side it was also possible to establish whether the osteoarthrotic changes had become increased in comparison with the time of injury and with the opposite side This type of progressive osteoarthrosis was diagnosed in 24 subjects (10%) none of whom had osteoarthrosis in the femorotibial joint of the injured side

Osteoarthrosis—irrespective of the genesis and the location—depended on the age of the subjects at the follow up examination Osteoarthrosis of the injured knee was found in 42 (39 %) of those over 60 years of age and in 29 (41%) of those under ($p<0.01$) Osteoarthrosis of the knee occurred twice as often in females as in males Osteoarthrosis of the injured patellofemoral joint was diagnosed in 20 subjects (28%) who were injured in a traffic accident or

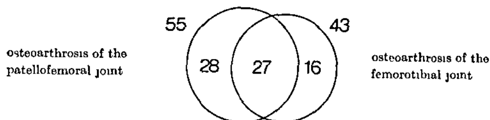


Fig 28 Osteoarthrosis of the injured knee of 71 subjects after patellar fracture

of changes were present in 67 subjects (27%) Out of these 56 were surgically treated The radiographic examination revealed these changes in almost all of those who had sustained partial or total excision of the patella

Osteoarthrotic changes were not diagnosed on the basis of slight formation of osteophytes and a normal height of the joint space without changes in the structure of the articular surface Slight osteoarthrosis was established if the formation of osteophytes was moderate and the joint space was slightly reduced with or without structural changes Moderate osteoarthrosis was present when the formation of osteophytes was moderate or pronounced the height of the joint space was moderately reduced and structural changes such as deformation of the articular surfaces and subchondral sclerosis were moderate Considerable osteoarthrosis was diagnosed when the formation of osteophytes and the reduction of the joint space were pronounced with a definite deformation of the articular surfaces with sclerosis and formation of cysts in the subchondral bone

Osteoarthrotic changes in the injured patellofemoral joint were observed in 55 subjects (22%) Out of these 33 had slight changes 15 moderate and seven considerable Osteoarthrotic changes in the femorotibial joint of the injured side were established in 43 subjects (18%) Out of these 28 had slight changes eleven moderate and four considerable The number of subjects with osteoarthrosis of the injured knee totalled 71 (29%) which is illustrated in *Fig 28*

In the patellofemoral joint of the opposite side osteoarthrotic changes were observed in 19 subjects (8%) Out of these seven had slight changes eight moderate and four considerable In the femorotibial joint of the opposite side osteoarthrotic changes were observed in 23 subjects (9%) Out of these 16 had slight changes six moderate and one considerable The total number of subjects with osteoarthrosis of the opposite side was 27 (11%) as demonstrated in Fig 29

Radiographs taken at the time of injury revealed osteoarthrotic changes in the injured knee joint in 35 subjects (9%)

As degenerative osteoarthrosis may occur simultaneously in both the patello

Table 18 Subjective symptoms correlated with various objective signs

Subjective symptoms	Objective signs				
Pain	Restricted range of mobility	Considerable reduction of force	Fibrous union and pseudarthrosis	Articular surface step ≧1 mm	Osteoarthrosis
No pain	7 ([illegible])	6 (1[illegible]%)	10 (48%)	1[illegible] (30%)	19 ([illegible]7%)
Slight	3 (11[illegible])	4 (11%)	3 (14%)	9 ([illegible])	16 ([illegible]2%)
Moderate	3 (11%)	6 (17[illegible])	6 ([illegible]9%)	10 ([illegible])	8 (11%)
Severe	14 (5[illegible])	19 (5[illegible]%)	2 ([illegible]9[illegible])	9 ([illegible]%)	[illegible] (40%)
Total	[illegible] (100%)	35 (100[illegible])	[illegible]1 (100%)	40 (100%)	71 (100%)

Out of the 27 subjects with a restricted range of mobility 22 (82%) had osteoarthrosis at the primary or the follow up radiographic examination Out of the 35 subjects with a considerable reduction of force 21 (60%) had osteoarthrosis at the primary or the follow up radiographic examination

Classification of results

The result was considered *excellent* if the subject was free from discomfort without pain or subjectively experienced impairment of function with a normal range of mobility of the knee joint and with equal force in the extensor apparatus of both knees The result was considered *poor* if the injury alone could be assumed to be the cause of pain at rest and/or pain during all kinds of activity Furthermore the result was regarded as poor if the injury alone could be assumed to be the cause of at least *two* of the following three symptoms and signs

1 Subjectively experienced impairment of function corresponding to a score exceeding 4 and 6 points respectively
2 Deficiency of extension exceeding 10 degrees and/or bending capacity to a flexed position of 90 degrees or less
3 Reduction of force of the extensor apparatus of the knee exceeding 30 per cent of the force of the uninjured knee

In all the other cases the result was considered *good* Subjects with a good result formed a heterogeneous group In this group were included in addition to those with a good result on account of the injury also those with a poor result that was not ascribable to the injury but instead probably caused by

by fall from height and 29 (19%) injured by other modes ($p>0.05$). After open fracture, osteoarthrosis of the injured patellofemoral joint was observed in 9 subjects (60%) and after closed fracture in 46 subjects (20%) ($p<0.01$). After comminuted fracture osteoarthrosis of the injured patellofemoral joint was diagnosed in 17 subjects (42%) and after other types of fracture in 38 (19%) ($p<0.01$). *Osteoarthrosis of the injured patellofemoral joint occurred* twice as often after operative as after non operative treatment (35% and 16% of the respective follow up series) ($p<0.01$). Osteoarthrosis of the femorotibial joint of the injured side occurred just as frequently after operative as after non operative treatment. The frequency of osteoarthrosis was as large after *osteosynthesis as after partial patellectomy (32% and 35% of the respective* follow up series). All four subjects who were radiographically examined after total patellectomy had osteoarthrotic changes in the femoral component of the injured patellofemoral joint.

There was no increase in the frequency of osteoarthrosis of the patello*femoral joint because of fibrous union and pseudarthrosis (24% contra 22% in the other series).*

Osteoarthrosis of the patellofemoral joint was found in 16 subjects (40%) with a step in the articular surface of the patella of 1 mm or more and in 35 (17%) in the other series ($p<0.01$ four cases of total patellectomy excluded). *Only seven of these 16 subjects had osteoarthrotic changes which* could be assumed to have been formed or developed as a result of the injury. Regarding only those with osteoarthrotic changes of the patellofemoral joint assumed to have been formed or developed as a result of the injury the frequency of osteoarthrosis was insignificantly higher in those with a step in the articular surface *of the patella of 1 mm or more as compared with the other* series ($p>0.05$). Osteoarthrosis of the injured patellofemoral joint was insignificantly *higher when there was enlargement of the patella (28% contra 22%* in the other series after excluding the cases of total patellectomy) ($p>0.05$). Osteoarthrosis of the injured knee was established in 28 *(42%)* of the 67 subjects who *had calcium bodies and bone resembling tissue in the surrounding areas* of the patella and 43 (24%) in the other series ($p<0.01$).

Correlations

Pain *connected with various objective signs* is stated in Table 18.

The subjects who had a restricted range of mobility and considerable reduction of force without pain were elderly subjects with osteoarthrosis irrespective of the injury. Half the number of subjects with fibrous union and pseudarthrosis felt no pain. Some subjects *with both osteoarthrosis* and an articular surface step of 1 mm or more were free from pain.

Table 18 Subjective symptoms correlated with various objective signs

Subjective symptoms	Objective signs				
Pain	Restricted range of mobility	Considerable reduction of force	Fibrous union and pseudarthrosis	Articular surface step ≧1 mm	Osteoarthrosis
No pain	7 ([illegible])	6 (17 [illegible])	10 (48%)	1[illegible] (30%)	19 ([illegible])
Slight	3 (11%)	4 (11%)	3 (14%)	9 ([illegible])	16 ([illegible]%)
Moderate	3 (11 [illegible])	6 (1[illegible]%)	6 ([illegible])	10 ([illegible]%)	8 (11%)
Severe	14 ([illegible])	19 (55%)	2 (9%)	9 ([illegible]%)	[illegible]8 (40%)
Total	27 (100%)	35 (100%)	[illegible]1 (100%)	40 (100%)	[illegible] (100%)

Out of the 27 subjects with a restricted range of mobility 22 (82%) had osteoarthrosis at the primary or the follow up radiographic *examination* Out of the 35 subjects with a considerable reduction of force 21 (60%) had osteoarthrosis at the primary or the follow up radiographic examination

Classification of results

The result was considered *excellent* if the subject was free from discomfort without pain or subjectively experienced impairment of function with a normal range of mobility of the knee joint and with equal force in the extensor apparatus of both knees The result was considered *poor* if the injury alone could be assumed to be the cause of pain at rest and/or pain during all kinds of activity Furthermore the result was regarded as poor if the injury alone could be assumed to be the cause of at least two of the following three symptoms and signs

1 Subjectively experienced impairment of function *corresponding* to a score exceeding 4 and 6 points respectively
2 Deficiency of extension exceeding 10 degrees and/or bending capacity to a flexed position of 90 degrees or less
3 Reduction of force of the extensor apparatus of the knee exceeding 30 per cent of the force of the uninjured knee

In all the other cases the result was considered *good* Subjects with a good result formed a heterogeneous group *In this* group were included in addition to those with a good result on account of *the injury* also those with a poor result that was not ascribable to the injury but instead probably caused by

another disease If it had been possible in these cases to assess the real result of the injury one or other of the subjects might have been referred either to the group excellent or to the group poor results

Of those who merely answered questionnaires none were referred to the group poor results However it cannot be excluded that one or other might have been included in the group poor results if a complete examination had been carried out

Of those who were clinically examined but not radiographically, two subjects were included in the poor results Possibly one of these or both could have been included in the group good results after complementary radiographic examinations which could have given evidence of osteoarthrosis not being connected with the injury

Pain at rest and/or pain during all kinds of activity was noted in 42 subjects In 16 of these the pain could depend on osteoarthrosis of the knee joint but with no relation to the injury A further seven had pain which could be caused by some other injury or disease The remaining 19 subjects were included in the group poor results owing to patellar fracture (Fig 31)

Impairment of function corresponding to a score exceeding 4 and 6 points respectively was subjectively experienced by 49 subjects In 26 of these the impairment of function could depend on osteoarthrosis some other disease or *injury without any sure relation to the patellar fracture In the group poor* results owing to patellar fracture the remaining 23 subjects were included (Fig 31)

Deficiency of extension exceeding 10 degrees and/or bending capacity to a flexed position of 90 degrees or less was observed in 17 subjects Eight of these had a restricted range of mobility which could depend on some other injury or disease especially osteoarthrosis

Reduction of force of the extensor apparatus of the injured knee exceeding 30 per cent of the force of the uninjured knee was recorded in 35 subjects Out of these 16 subjects had reduced force which could depend on other disease or injury especially osteoarthrosis

Deficiency of extension exceeding 10 degrees and/or bending capacity to a flexed position of 90 degrees or less and/or reduction of the force of the extensor apparatus of the knee exceeding 30 per cent was established in 46 subjects To the group poor results owing to fracture of the patella 22 of these were included (Fig 31)

A total of 73 subjects had one or several subjective symptoms or objective signs according to the criteria on which a poor result was based (Fig 31)

Excellent results were achieved in 145 (45%) and good results in 150 subjects (47%) The results were *poor in 25 (8%) subjects* The distribution of the results among males and females is indicated in Fig 32

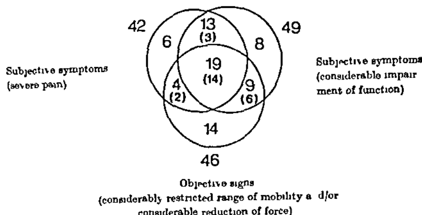


Fig 31 Subjective symptoms and objective signs of 73 subjects with a poor result in some respect The figures in brackets indicate the subjects who according to the classification were considered to belong to the group poor results owing to patellar fracture

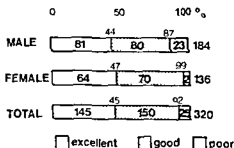


Fig 3 Late results of patellar fractures in males and females

There was no difference in the distribution of the results among those over 60 years of age as compared with those under (Fig 33)

After patellar fractures caused by traffic accidents or falls from height poor results were more common than after patellar fractures caused by falls in the same plane and by direct blows ($p < 0.01$) (Fig 34)

There were poor results of open fractures in 30 per cent and of closed fractures in 6 per cent ($p < 0.01$) (Fig 35)

In subjects who had a concomitant injury the result was more often poor as compared with those who had no other injury ($p < 0.01$) (Fig 36)

The results of all types of transverse fracture and comminuted fractures

another disease If it had been possible in these cases to assess the real result of the injury one or other of the subjects might have been referred either to the group excellent or to the group poor results

Of those who merely answered questionnaires none were referred to the group poor results However, it cannot be excluded that one or other might have been included in the group poor results if a complete examination had been carried out

Of those who were clinically examined, but not radiographically, two subjects were included *in the poor results Possibly one of these or both could* have been included in the group good results after complementary radiographic examinations which could have given evidence of osteoarthrosis not being connected with the injury

Pain at rest and/or pain during all kinds of activity was noted in 42 subjects In 16 of these the pain could depend on osteoarthrosis of the knee joint but with no relation to the injury A further seven had pain which could be caused by some other injury or disease The remaining 19 subjects were included in the group poor results *owing* to patellar *fracture* (Fig 31)

Impairment of function corresponding to a score exceeding 4 and 6 points respectively was subjectively experienced by 49 subjects In 26 of these the impairment of function could depend on osteoarthrosis some other disease or injury without any sure relation to the patellar fracture *In* the group poor results owing to patellar fracture the remaining 23 subjects were included (Fig 31)

Deficiency of extension exceeding 10 degrees and/or bending capacity to a *flexed* position of 90 degrees or less was observed in 17 subjects *Eight of these* had a restricted range of mobility which could depend on some other injury or disease especially osteoarthrosis

Reduction of force of the extensor *apparatus of the injured knee exceeding* 30 per cent of the force of the uninjured knee was recorded in 35 subjects Out of these 16 subjects had reduced force which could depend on other disease or injury especially osteoarthrosis

Deficiency of extension exceeding 10 degrees and/or bending capacity to a *flexed* position of 90 degrees or less and/or reduction *of the force of the* extensor apparatus of the knee exceeding 30 per cent was established in 46 subjects *To the group poor results* owing to fracture of the patella 22 of these were included (Fig 31)

A total of 73 subjects had one or several subjective symptoms or objective signs according to the criteria on which a poor result was based (Fig 31)

Excellent results were achieved in 145 (45%) and good results in 150 subjects (47%) The results were poor *in* 25 *(8%)* subjects *The* distribution of the results among *males and females is indicated in* Fig 32

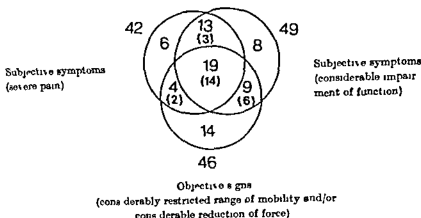


Fig 31 Subjective symptoms and objective signs of 73 subjects with a poor result in some respect The figures in brackets indicate the subjects who according to the classification were considered to belong to the group poor results owing to patellar fracture

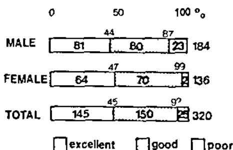


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The results of all types of transverse fracture and comminuted fractures

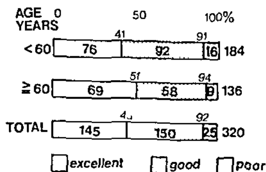


Fig 33 Late results of patellar fractures in various age groups

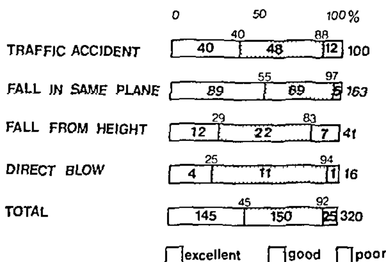


Fig 34 Late results of patellar fractures as related to the mode of injury

were equivalent (Fig 37) The result was poor in one subject who had sustained a longitudinal lateral fracture Also after longitudinal medial apical and basal fractures which generally were extra articularly situated the result was poor only in exceptional cases (Fig 37)

When there was only slight separation of the fragments the result was excellent or good in 98 per cent (Fig 38) *If the diastasis was considerable suggesting an extensive tear of the lateral expansions the result was poor in 20 per cent*

After non operative treatment the result was excellent in 118 subjects *(56%) good in 92 (43%) and poor in 2 (1%) After operative treatment it was* excellent in 27 subjects (25%) good in 58 (54%) and poor in 23 (21%) Fig 39

The results of various methods of operative treatment are stated in Fig 40

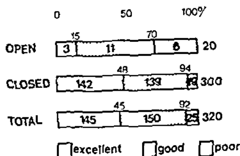


Fig 35 Late results of open and closed patellar fractures

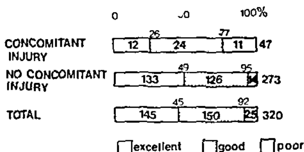


Fig 36 Late results of patella fractures with and without concomitant injuries

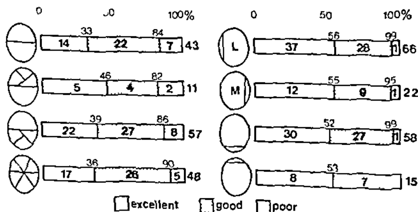


Fig 37 Late results of various types of patellar fracture

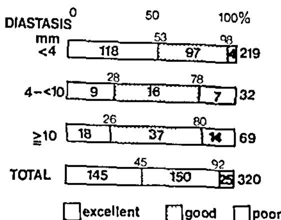


Fig 38 Late results of patellar fractures with regard to the separation between the fragments

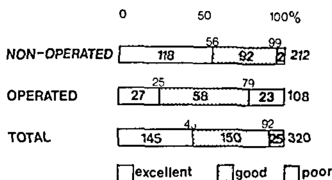


Fig 39 Late results of non operative and operative treatment of patellar fractures

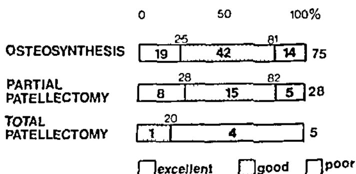


Fig 40 Late results of various methods of operative treatment for patellar fractures

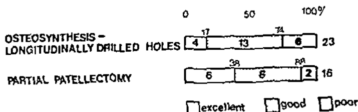


Fig 41 Late results of transverse patellar fractures with a split lower pole treated by means of either osteosynthesis or partial patellectomy

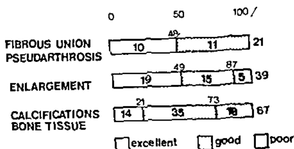


Fig 42 Late results of fibrous union and pseudarthrosis of enlargement of the patella and of presence of calcium bodies and bone resembling tissue in the surroundings after patellar fracture

After osteosynthesis and partial patellectomy poor results were equally frequent (19% and 18% of the respective follow up series) In none of the cases of total patellectomy was the result excellent

In transverse fractures with a split lower pole 23 subjects were treated with osteosynthesis with a stainless steel wire inserted through longitudinally drilled holes and 16 with partial patellectomy (Fig 41) The results were poor in 6 subjects (26%) after osteosynthesis and in 2 (12%) after partial patellectomy ($p > 0.05$)

With fibrous union and pseudarthrosis 10 subjects (48%) had an excellent result 11 (52%) a good and none a poor (Fig 42)

Only one of 22 non operatively treated subjects who had a persisting step in the articular surface of the patella of 1 mm or more revealed at the follow up examination had a poor result the result was excellent in 9 (41%) and

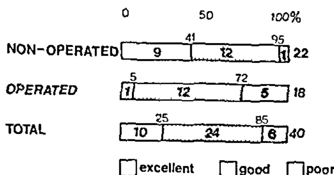


Fig 43 *Late result in 40 subjects with a persisting step in the articular surface of the patella of 1 mm or more after patellar fracture*

good in 12 subjects (54%), Fig 43 Five subjects (28%) of those operatively treated with a *persisting step in the articular* surface of the patella of 1 mm or more were referred to the group poor results *only one achieved an excellent* result

The result of enlargement of the patella radiographically verified and of the presence of calcium bodies and bone resembling tissue in the surroundings are indicated in Fig 42

All subjects referred to the group poor results owing to patellar fracture stated that they were not restored when the treatment terminated and that the discomfort continued When the treatment was ended certificates of disablement were issued to 17 subjects owing to sequelae of the patellar fracture 16 of whom were followed up Five subjects in this investigation referred to the group poor results were not considered by the insurance companies to have reduced capacity for work exceeding 10 per cent (Table 19)

Table 19 Late results of 16 subjects as classified by insurance companies with regard to compensation for reduced capacity for work after patellar fracture

Compensation	Results			
	Excellent	Good	Poor	Total
No compensation	2	2	[illegible]	9
Temporary compensation	[illegible]	1	1	[illegible]
Lifelong compensation		1	4	5

CHAPTER V

DISCUSSION AND CONCLUSIONS

Series

Fracture of the patella strikes subjects of all ages The mean age in this series was 48 years which is higher than reported by other authors In conformity with Nummi (1971) the mean age of males was considerably lower as compared with females

The percentage of injured males was 57 which is less than stated in most other reports

Several authors state that fracture of the patella occurs in an increasing frequency as a result of traffic accidents In agreement with Schonbauer (1959) and Nummi the present series does not support this statement In males younger than 50 years of age traffic accidents however were the most common cause of patellar fracture The classification of different types of patellar fracture varies with the authors and comparisons are difficult to make The number of longitudinal lateral fractures was remarkably large probably depending on a careful radiographic examination and furthermore on the fact that the series similar to that of Nummi included ambulant cases Both these investigations show—as opposed to an earlier concept—that the longitudinal lateral fracture is a common type of patellar fracture In conformity with Smillie (1970) it was found that a number of different types of fracture may result from the same mode of injury From the appearance of the fracture no sure conclusions could be drawn as to the modes of injury

The injury to the lateral expansions was of decisive importance for selecting the method of treatment With a diastasis of 4 mm or more the tear of the lateral expansions was so widespread that there was loss of active extension in most of the cases The operatively treated patients constituted 32 per cent of the entire series This group was of the same magnitude as that of Nummi (31%)

The post operative complications were few and of the same proportions as those reported by other authors (cf Nummi 5%) However it is remarkable that no cases of thrombosis or thrombo embolism were diagnosed

Some authors hold the opinion that several days should elapse after the

5

injury before applying a plaster cast In this series a plaster cast was applied immediately As a rule this did not involve any disadvantages However two patients contracted paralysis of the peroneus after the plaster was applied

Re operation was rarely necessary Only in exceptional cases (4 cases) was there reason to remove the metal wire Nummi reported 62 extirpations of the metal wire frequently done because of pain where the wire knot was tied The low frequency of extirpation of the metal wire in this series no doubt depended on the twined end of the wire having been recessed into the patella

Conclusive comparisons with regard to periods of sick leave and compensation for disablement between the various series are frequently difficult to make as the social and economical advantages vary with the diffent countries The periods of sick leave in this investigation were equivalent to those of Nummi after both non operative and various types of operative treatment

At the follow up study it was in conformity with other authors possible to establish that subjective symptoms occurred to a great extent after patellar fracture As the period of observation was almost nine years and the mean age at the follow up examination was 53 years it is necessary to bear in mind that there may be other reasons for the joint discomfort than the sequelae of patellar fracture

Restricted range of mobility was found mainly in elderly subjects and in those who had osteoarthrosis Contrary to Ehlert (1963) a long period of immobilization in plaster was not found to prevent the recovery of mobility at long sight

Measuring of the circumference of the thigh should be combined with recording of the force of the extensors of the knee in order to allow an adequate interpretation of the quadriceps function This especially applies when the circumference of both legs is equal in size The figures obtained possibly did not represent the maximal force which according to Clarke *et al* (1950) and Hallen & Lindahl (1967) is reached when the knee joint is flexed through 60–75 degrees The figures recorded were the same as those obtained from an equivalent age group by other Swedish authors

As other authors have pointed out the force of the extensors of the knee was often reduced after fracture of the patella and particularly after total patellectomy The force of the extensor apparatus of the knee is no doubt affected also by factors other than the reduced length of the lever (cf Stener 1969) e g painful hydrops of the joint (de Andrade Grant & Dixon 1965) and inflammatory changes (Tiselius 1969) It is possible that the force of extension after healing of the patellar fracture depends on the tear of the lateral expansions at the time of injury

The theory supported by several authors (cf Schonbauer 1955 J Bohler 1961 Nummi 1971) that steps in the articular surface of the patella provoke

osteoarthrosis has not been realized in this investigation An increase in the frequency of osteoarthrosis of the patellofemoral joint assumed to have been formed or developed as a result of the injury was indeed recorded when there was a step of the articular surface amounting to 1 mm or more but the difference in frequency was not significant Furthermore quite a few subjects with a step in the articular surface of the patella experienced no pain

Thomson (1942) maintained that enlargement of the patella did not occur after partial patellectomy In this investigation enlargement of the patella occurred after both partial patellectomy and osteosynthesis and furthermore after both non operative and operative treatment As opposed to Sorensen (1964) there was no increase in the frequency of osteoarthrosis with enlargement of the patella in this investigation

Many authors have pointed out that osteoarthrosis may set in after a joint lesion In this investigation there were possibilities of establishing the development of osteoarthrosis which could be secondary to the injury and of that which could depend on other circumstances

A rather high frequency of osteoarthrosis of a primary type could be expected as the higher age groups included many females (Hernborg 1969) The frequency of osteoarthrosis as reported in other series is probably too high because no distinction has been made between primary and secondary osteoarthrosis Nummi agrees that his figures are too high Sorensen mentions that only in exceptional cases had he access to radiographs taken at the time of injury and thus was unable to assess development of osteoarthrosis Without doubt however osteoarthrosis may develop as a direct result of the injury In this series there was an increase in the frequency of osteoarthrosis after open fracture comminuted fracture and operative treatment whilst the choice of operation method seemed to be of secondary importance Some of the subjects with osteoarthrosis were free from pain

Poor results were recorded in 8 per cent of the entire series (25/320) In the group poor results Fontaine *et al* (1965) included 10 *per cent* (8/78) Villiger (1965) 4 per cent (3/82) Detmar (1966) 7 per cent (7/104) Struck (1966) 6 per cent (5/82) and Nummi (1971) 8 per cent (32/391)

There was a distinct male predominance among those included in the poor results following patellar fracture On the other hand the late results were equivalent with respect to age over and under 60 years The mode of injury and other circumstances connected with the trauma were essential Traffic injury and fall from height open fracture and concomitant injury were factors which contributed to a poor result

Excellent and good results of longitudinal apical and basal fractures were achieved to a large extent In these fractures the injury to the lateral expansions was often slight This investigation does not support the opinion held

for instance by de Palma (1954) that longitudinal lateral fractures should be treated surgically in order to avoid future discomfort Despite the fact that fibrous union was most common in longitudinal lateral fractures the frequency of poor results was low

Excellent good and poor results were recorded to the same extent in trans verse types of fracture as in comminuted fractures The type of fracture seemed to be of secondary importance as compared with the injury to the lateral expansions

In conformity with other authors, this series revealed to a great extent excellent and good results of the fractures to which non operative treatment was applicable In this series poor results were noted in 1 per cent (2/212) of fractures treated non operatively *In the group poor after non operative* treatment Fontaine *et al* included 5 per cent (1/20) Villiger 5 per cent (1/21) Detmar 11 per cent (3/27), Struck 4 per cent (2/51) and Nummi 4 per cent (10/236)

In the cases treated operatively, the results were less satisfactory as ex pected Poor results *in this series amounted to 21 per cent (23/108)* The corre sponding figures of poor results in other series are lower Fontaine *et al* reported 12 per cent (7/58) Villiger 3 per cent (2/61) Detmar 5 per cent (4/77) Struck 10 per cent (3/31) and Nummi 14 per cent (22/155)

However the results cannot simply be compared The late results of a joint lesion can be assumed to depend on other conditions than the injury and often the extent of consideration taken to this fact is not clearly expressed Further more the methods of analysis and the criteria vary with different authors

Excellent good and poor results were recorded to the same extent after methods used for restoration of normal anatomy and after partial patellectomy Too few patients were subjected to total patellectomy for any conclusions to be drawn as to the value of this method of operation The patients on whom total excision of the patella was performed all had open fractures The most common method of operation employed in attempting to restore the anatomy was stainless steel wire inserted through longitudinally drilled holes according to Payr It was used both for transverse and comminuted fractures Operative treatment of transverse fractures with a split lower pole could be performed either by osteosynthesis with a stainless steel wire inserted through longi tudinally drilled holes or by partial patellectomy In the follow up study there were 23 and 16 subjects respectively who had been operated on by the use of these methods Partial patellectomy tended to give better results of this particular type of fracture as compared to osteosynthesis but the groups of patients were small and the differences not significant

In no case of fibrous union and pseudarthrosis were the late results poor a fact experienced also by Nummi

A step in the articular surface of the patella of 1 mm or more did not affect the late results of non operatively treated cases Nor did a persistent step in the articular surface of the patella of 1 mm or more significantly increase the frequency of poor results of operatively treated cases This may imply that it is not essential to attain exact reposition and that a difference of level of 2–3 mm between the fragments can be accepted and treated non operatively if there is no other indication of operation

Enlargement of the patella did not affect the late results Nor did the enlargement provoke osteoarthrosis and consequently this finding is of little clinical importance Calcium bodies in the surroundings of the patella and bone resembling tissue in the quadriceps tendon and in the patellar ligament gave poor results approximately to the extent expected in view of the fact that most of the patients had been treated by surgery The frequency of osteoarthrosis with these above mentioned changes was also just as high as that obtained after operative treatment The clinical importance of these changes is probably insignificant

Finally it is remarkable that all the subjects with a poor result pointed out that they were not restored at the end of the treatment and that the discomfort continued

Conclusions

Certain misgivings are involved with fracture of the patella inasmuch as persistent disability may result in the form of pain subjectively experienced reduction of function restricted range of mobility reduced force of extension of the knee and osteoarthrosis On the basis of a follow up study of 320 patients subjected to patellar fracture the following was found

1 The mechanism of injury and the severity of the trauma affect the late results of patellar fracture In traffic accidents and falls from height and also in open fractures and concomitant injuries there will be a greater risk of a poor result
2 Various types of fracture may result from the same mode of injury A particular type of fracture is no true indication of the mode of injury Nor is it generally possible to give a sure statement of the prognosis on the basis of the type of fracture However there is a good prognosis for longitudinal apical and basal fractures in all probability depending on the injury to the lateral expansions being slight in most of these fractures
3 The patient's capacity for extension of the knee the separation and the difference of level between the fragments are factors to be borne in mind when deciding whether non operative or operative treatment shall follow When the extension capacity is preserved the separation of fragments is

for instance, by de Palma (1954) that longitudinal lateral fractures should be treated surgically in order to avoid future discomfort Despite the fact that fibrous union was most common in longitudinal lateral fractures the frequency of poor results was low

Excellent, good and poor results were recorded to the same extent in trans verse types of fracture as in comminuted fractures The type of fracture seemed to be of secondary importance as compared with *the injury to the* lateral expansions

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However the results cannot simply be compared The late results of a joint lesion can be assumed to depend on other conditions than the injury and often the extent of consideration taken to this fact is not clearly expressed Further more the methods of analysis and the criteria vary with different authors

Excellent good and poor results were recorded to the same extent after methods used for restoration of normal anatomy and after partial patellectomy Too few patients were subjected to total patellectomy for any conclusions to be drawn as to the value of this method of operation The patients on whom total excision of the patella was performed all had open fractures The most common method of operation employed in attempting to restore the anatomy was stainless steel wire inserted through longitudinally drilled holes according to Payr It was used both for transverse and comminuted fractures Operative treatment of transverse fractures with a split lower pole could be performed *either by osteosynthesis with a stainless steel wire* inserted through longi tudinally drilled holes or by partial patellectomy In the follow up study there were 23 and 16 subjects respectively who had been operated on by the use of these methods Partial patellectomy tended to give better results of this particular type of fracture as compared to osteosynthesis but the groups of *patients were small and the differences* not significant

In no case of fibrous union and pseudarthrosis were the late results poor a fact experienced also by Nummi

Restoration of normal anatomy is recommended for transverse fractures with two large fragments and comminuted fractures when the articular surface can be restored

Repair of the quadriceps apparatus retaining one large fragment is recommended in transverse fractures with a split upper or lower pole and in comminuted fractures if the articular surface cannot be restored and there is a large fragment including more than half of the patella

Total excision of the patella never seems to be a treatment of choice but is *recommended in exceptionally severe cases e g* open comminuted fractures or when other methods of treatment have failed

Irrespective of the operation method selected it is essential that the tear of the lateral expansions be identified and that the anatomy be accurately restored

The post operative procedure is the same irrespective of the operation method elected Immobilization in a plaster cast with the knee flexed through *5–10* degrees during 6–7 *weeks* is indicated The patient should be instructed to practice active exercise of the quadriceps muscles (Svantesson 1971) When the quadriceps muscles can be contracted leg raising is instituted Weight bearing and mobilization on crutches as protecting support are permitted when the patient can lift his leg When the plaster cast has been discarded the patient should be instructed how to practice active exercises Primarily this includes isometric and later also isotonic extension and flexion exercises—in the beginning without and later with increasing resistance The exercises should be carried out under the supervision of a physiotherapist

3–4 mm or less, and the difference of level is 2–3 mm or less excellent and good late results can be expected after non operative treatment The prognosis is less good after operative than after non operative treatment no doubt, owing to the more serious injury necessitating operative treatment The choice of operation method is probably of secondary importance as compared with the mode of injury and other circumstances involved with the trauma

4 After a joint lesion such as a fracture of the patella subjective symptoms and objective signs may depend—particularly with increasing age—on circumstances other than sequelae of the injury especially osteoarthrosis

5 It is difficult to come to any definite conclusions when comparing between different series owing to the varying criteria used for classification However after perusal of the literature on the subject and after study of this series, there has not been any reason to recommend the introduction of another method of treatment nor to advise against the use of any of the methods which were applied in this series

Suggestion of treatment

On the basis of the literature and this series the following is recommended

Non Operative Treatment

The *patient s capacity for lifting his leg with the knee extended the extent* of separation and the difference of level between the fragments must be considered when deciding between non operative and operative treatment When the extension *capacity of the knee is preserved the diastasis is 3–4 mm or less* and the step in the articular surface is 2–3 mm or less non operative treatment is advised If there is loss of active extension of the knee and the diastasis is less than 4 mm the patient *should be hospitalized and the joint should be* punctured pending the development A severe tear of the lateral expansions involved with this diastasis is most unlikely

In non operative treatment immobilization in a *plaster cast during four* weeks is generally sufficient the time of which can be reduced in cases of longitudinal fracture The patient should be instructed to practice active exercise of the quadriceps muscles Weight bearing is permitted *Crutches as* protecting support are recommended

Operative Treatment

Loss of active extension of the knee and a diastasis of more than 3–4 mm and a step in the articular surface of the patella of more than 2–3 mm are indications for operation

bilized in a plaster cast was two months and of those operated on four months The median period of sick leave was insignificantly shorter after partial patellectomy than after osteosynthesis

Follow up examination was carried out 5–12 years after the injury The mean time of observation was 8 9 years The late results of 320 subjects—totalling 91 per cent of those alive at the time of the follow up—were reported A questionnaire was filled up A clinical examination was performed on 271 subjects Pain and subjectively experienced impairment of function were recorded as well as the range of mobility of the knee joint the circumference of the thigh and the force of the extensors of the knee The radiographic examination of both knee joints in 246 subjects gave evidence of union fibrous union pseudarthrosis cerclage breakage step in articular surface enlargement of the patella calcium bodies and bone resembling tissue in the surroundings and formation and development of osteoarthrosis

70 per cent of the subjects were satisfied and stated that the injury had not caused persisting discomfort 59 per cent of the non operatively and 30 per cent of the operatively treated subjects felt no pain A normal function was subjectively experienced by 78 per cent of the non operatively and 36 per cent of the operatively treated subjects

Deficiency of extension of the knee was recorded in 6 per cent and bending capacity to a flexed position of less than 120 degrees was noted in 10 per cent The circumference of the thigh of the injured leg was reduced in 24 per cent The extension force of the knee was reduced in 37 per cent Reduction of force occurred to a greater extent when the separation between the fragments measured 4 mm or more

Fibrous union was more often found in longitudinal lateral fractures than in other types of fracture but caused no poor results Pseudarthrosis was recorded in 3 per cent and occurred after both non operative and operative treatment no ca e of poor results was noted A step in the articular surface of the patella of 1 mm or more was observed in 40 subjects (17%) half of whom were operated upon the majority according to the method of osteosynthesis with a stainless steel wire inserted through longitudinally drilled holes There was possibly no relation between a step in the articular surface and formation and development of osteoarthrosis in the patellofemoral joint caused by the injury Enlargement of the patella as well as calcium bodies and bone resemb ling ti sue in the patellar surroundings did not seem to be of clinical *importance* Formation and development of o teoarthrosis could result from the injury but the occurrence of osteoarthrosis was often independent of the injury and was mainly seen in females in advanced ages

Excellent results were achieved in 45 per cent and good results in 47 per cent while poor results were noted in 8 per cent There was a decided male

CHAPTER VI

SUMMARY

The series includes 416 patients who were radiographically examined in Goteborg during the period 1959–1964 because of injury to the knee and the *diagnosis was a fresh fracture of the patella*

57 per cent were males and 43 per cent females the mean age was 42 and 54 years, respectively The maximum of frequency for males was reached between the ages of 30 and 39 years, and for females between 60 and 69 years

The most common mode of injury was a fall in the same plane (54%) the next common various types of traffic accidents (28%) In 6 per cent there was an open fracture and in 15 per cent a concomitant injury which in almost half of the cases involved the lower extremities

Transverse fractures were diagnosed in 34 per cent comminuted in 16 per cent longitudinal lateral in 22 per cent and others including longitudinal medial apical and basal fractures in 28 per cent The different modes of injury exhibited a large variety of fractures 51 per cent of the fractures were non dislocated and in a total of 70 per cent the diastasis was less than 4 mm The step in the articular surface in this dislocation was nearly always less than 3 mm A diastasis of at least 4 mm was established in 30 per cent A loss of active function of the quadriceps muscles was found in 33 per cent

Non operative methods of treatment were considered advisable in preserved extension capacity of the knee diastasis less than 4 mm and a step in the articular surface less than 3 mm 287 fractures in 282 patients (68%) were treated non operatively usually with immobilization in a plaster cast during 3–5 weeks 135 fractures in 134 patients (32%) were subjected to surgery The most common method of operation was osteosynthesis with a stainless *steel wire inserted through longitudinally drilled holes* Partial patellectomy was the next common method of operation while total excision of the patella was performed only exceptionally All the methods of operation were followed by immobilization in plaster the median period of which was 6 5 weeks Complications occurred in 5 per cent Re operation was performed in 5 per cent The most common re operation was mobilization of the patella performed owing to restricted mobility of the knee joint after the plaster cast had been discarded

The median period of sick leave of non operatively treated patients immo

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Goteborg in May 1972

Åke Bostrom

predominance among those with poor results Injury owing to traffic accidents and fall from height open fracture and concomitant injury entailed a greater risk of a poor result After longitudinal, apical, and basal fractures, in which the tear of the lateral expansions was frequently slight, the late results were better than after transverse and comminuted fractures which more often involved a considerable injury to the lateral expansions The result of patients non operatively treated, was excellent or good in 99 per cent After operative *treatment the result was excellent or good in 79 per cent The late results* were equivalent after osteosynthesis and partial patellectomy, but worse after total excision of the patella performed only in selected cases with open fracture

On the basis of a survey of the literature and on this investigation it has been possible to come to some conclusions and to give recommendations for the treatment of acute fracture of the patella

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REFERENCES

Ahlback S (1968) Osteoarthrosis of the Knee A Radiographic Investigation Thesis Acta radiol (Stockh) Suppl 277

Anderson L D (1971) in Campbell s Operative Orthopaedics 5th ed A H Crenshaw editor The C V Mosby Company Saint Louis

de Andrade J R Grant C & Dixon A St J (1965) Joint Distension and Reflex Muscle Inhibition in the Knee J Bone Jt Surg 47 A 313–322

Baumgartl F (1964) Das Kniegelenk Springer Verlag Berlin

Berger (1892) Bull et mém Soc de chir de Paris T 18 523–525 (Quoted by Thiem see below)

Bernays A (1878) Die Entwicklungsgeschichte des Kniegelenkes des Menschen mit Bemerkungen über die Gelenke in allgemeinen Morph Jb 4 (Quoted by Baumgartl see above)

Black J K & Conners J J (1969) Vertical Fractures of the Patella Sth med J (Bgham Ala) 62 76–77

Blodgett W E & Fairchild R D (1936) Fractures of the Patella Results of Total and Partial Excisions of the Patella for Acute Fracture J Amer med Ass 106 2121–2125

Borsalino G (1964) The Surgical Treatment of Fractures of the Patella Experimental Study Panminerva med 6 123–125

Brewerton D A (1955) The Function of the Vastus Medialis Muscle Ann phys Med 2 164–168

Brooke R (1937) The Treatment of Fractured Patella by Excision A Study of Morphology and Function Brit J Surg 24 733–747

Bruce J & Walmsley R (1942) Excision of the Patella Some Experimental and Anatomical Observations J Bone Jt Surg 24 311–325

Burny F (1969) Resultats éloignés du traitement des fractures récentes de la rotule *Acta orthop belg 35 392–398*

Backlund L & Nordgren L (1968) A New Method for Testing Isometric Muscle Strength under Standardized Conditions Scand J Clin Lab Invest 21 33–41

Bohler J (1961) Behandlung der Kniescheibenbruche Osteosynthese Teilexstirpation Exstirpation Dtsch med Wschr 86 1209–1212

Bohler L (1951–1957) Die Technik der Knochenbruchbehandlung 12–13 ed Verlag Wilhelm Maudrich Wien

Castaing J Castellani L Plisson J L & Delplace J (1969) La patellectomie totale Technique et resultats Rev Chir orthop 55 259–278

Clarke H H Elkins E C Martin G M & Wakim K G (1950) Relationship Between Body Position and the Application of Muscle Power to Movements of the Joints Arch phys Med 31 81–89

Clein L J & Rostrup O (1964) An Investigation into Clinical and Experimental Patellectomy with the Use of a New Prosthesis Canad J Surg 7 88–92

Cohn B N E (1944) Total and Partial Patellectomy An Experimental Study Surg Gynec Obstet 79 5 6–536

Crenshaw A H & Wilson F D (1954) The Surgical Treatment of Fractures of the Patella Stl med J (Bgham Ala) 47 "16–" 0

Crock H V (196) The Arterial Supply and Venous Drainag of the Bones of the Human Knee Joint Anat Rec 144 199–218

Dethloff J (1956) Behandlungserg bnisse verschied ner Operationsmethoden bei Patella frakturen Acta orthop scand 2. 296–309

D tmar S J (1966) The Treatment of Patellar Fractures Arch. chir neerl 18 109–118

Diebold O (1927) Über Kniesch ibenbrüche im Kindesalter Lang nbecks Arch klin Chir 147 664–681

Duthie H L & Hutchinson J P (1958) The Results of Partial and Total Excision of the Patella J Bone Jt Surg 40 B 7.–81

Ehlert C (1963) Behandlungserg bnisse nach Kniesch ibenteilentfernung Mschr Un fallh lk 66 237–2 9

Fontaine R Muller J N Lang G & Dayeh S (1965) Les fractures de la rotule Statistiques et résultats de cent cas de fractures récentes Acta chir belg 64 535–5.1

Forg M (1959) Die Behandlung querer Kniescheibenbrüche mit Kompression der Fragmente Chirurg 30 36 –365

Frank l V H & Burstein A H (19 0) Ortopaedic Biom chan cs Lea & Febiger Phila delphia

Friberg S (1941) Über Total xstirpationen der Patella Acta chir scand 85 361–388

Fürma er A (1933) Beitrag zur Mechanik der Patella und des Gesamtkniegelenkes. Arch orthop Unfall Chir 46 78–90

G g nbau r C (1876) Zur Morphologie d r Gl edmassen der W rbeltiere Morph Jb 2 (Quoted by Baumgartl see above)

Giebel M G Krahl H & Sabr W (1963) Die Te lpatell ktomie be m Kniescheiben bruch Mschr Unfallheilk 72 398–401

Hach z Leblanc M (1958) Ostéosynthèse de rotule et cerclage fonctionn l Acta orthop belg 4 10 –113

Hallen L G & Lindahl O (1967) Muscle Fu ct on n Knee Extens on An EMG Stu ly A ta orthop scand 38 434–444

Haxto H (1945) The Function of the Patella and the Effects of its Excis on Surg Gynec Obstet 80 389–395

H neck A I (1909) The Modern Operative Treatment of Fractures of the Patella Surg Gynec Obstet 9 177– 48

Hernbe g J (1969) Knäledsarthrosens naturalhistor a Foredrag vid Medicinsk R ks. stämma Stockholm

H rsch C (1944) A Contribution to the Pathogenesis of Chondromalacia of the Patella A Physical H st logic and Chemical Study Thes s Acta chir scand Suppl. 83

H rsch C (1966) O teosyntes ut ec kling och probl m Svenska Lak Tidn 63 4714–4716

Huggl r A (1964) Di Zuggurt ing d r Patella Z Unfallm. Beruf kr 57 327 332

Hook O & Torn all G (1969) Apparatus and Method for Determinat on of Isometric Muscl Strength in Man Scand J Rehab Med 1 13–14

Jan L Viernste n K & Les esky H W (1969) Über d e Patell ktom e und ihre Spat ergel nisse Arch orthop Unfall Chir 66 98– 96

J nck G (193) Anat Anz 74 .89 (Quoted by Baumgartl see above)

Jene nius H (193) On the Result of Excis on of the Fractured Patella Acta chir scand 10 .– 84

Jonasch E (1964) Das Kniegelenk Walter de Gruyter & Co Berlin
Järvinen A (1942) Über die Kniescheibenbruche und ihre Behandlung mit besonderer Berücksichtigung der Dauerresultate im Licht der Nachuntersuchungen Acta Soc Med Duodecim 32 80–176
Kellgren J H & Lawrence J S (1957) Radiological Assessment of Osteo Arthrosis Ann rheum Dis 16 494–502
Kellgren J H (1963) The Epidemiology of Chronic Rheumatism Volume II Atlas of Standard Radiographs of Arthritis Blackwell Scientific Publications Oxford
Knutsson F (1941) Über die Rontgenologie des Femoropatellargelenks sowie eine gute Projektion fur das Kniegelenk Acta radiol (Stockh) 22 371–376
Kocher Th (1890) Zur Behandlung der Patellarfraktur Zbl Chir 7 3?1 (Quoted by Baumgartl see above)
von Lanz T & Wachsmuth W (1938) Praktische Anatomie Bd 1 Teil 4 Bein und Statik Springer Verlag Berlin
Lieb F J & Perry J (1968) Quadriceps Function An Anatomical and Mechanical Study *Using Amputated Limbs J Bone Jt Surg 50 A 1535–1548*
Lieb F J & Perry J (1971) Quadriceps Function An Electromyographic Study Under Isometric Conditions J Bone Jt Surg 53 A 749–7?8
Lindahl O Movin A & Ringqvist I (1969) *Knee Extension Measurement of the* Isometric Force in Different Positions of the Knee joint Acta orthop scand 40 79–85
Lister A *(1877) A New Operation for Fracture of the Patella Brit med J 2 8?0 (Quoted* by Thiem see below)
Madlener M J & Paas H R (1930) Über Patellarfrakturen und ihre Folgezustande unter *besonderer Beruecksichtigung der Arthritis deformans Langenbecks Arch* klin Chir 156 445–462
Magnuson P B (1936) Fractures 2nd ed J B Lippincott Company Philadelphia
Maquet P *(1969)* Biomécanique du genou et gonarthrose Rev méd Liège *24 170–19?*
McKeever D C (1955) Patellar Prosthesis J Bone Jt Surg 37 A 1074–1084
Moberg F (1944) On the Operative Therapy and Prognosis in Fracture of the Patella Acta chir scand *90 295–316*
Morrison J B (1969) Function of the Knee Joint in Various Activities Bio med Engng 4 573–?80
Muller M E Allgower M & Willenegger *H (1970) Manual of Internal Fixation Tech* nique Recommended by the AO Group Springer Verlag Berlin
Nowak W & Senst W (1968) Die Patellafraktur als Folge des Auto oder Motorrad unfalls Mschr Unfallheilk *71 548–553*
Nummi J (1971) Fracture of the Patella A Clinical Study of 707 Patellar Fractures Thesis Ann Chir Gynaec Fenn Suppl 179
O Donoghue D H Tompkins F & Hays M B (19??) Strength of Quadriceps Function After Patellectomy West J Surg 60 159–167
O Donoghue D H (1958) Treatment of Fractures of the Patella Northw Med (Seattle) 57 1?9?–1600
de Palma A F (19?4) Diseases of the Knee J B Lippincott Company Philadelphia
de Palma A F *(1959) The Management of Fractures and Dislocations* W B Saunders Company Philadelphia
de Palma A F & Flynn J J (19?8) Joint Changes Following Experimental Partial and Total Patellectomy J Bone Jt Surg *40 A 39?–413*

Paschold K (1958) Über Patellarfrakturen und ihre Behandlungsergebnisse unter besonderer Berucksichtigung der Arthrosis deformans Zbl. Chir 83 153 -1541

Payr E (1917) Zur operativen Behandlung der Kniegelenksteife nach langdauernder Ruhigstellung Zbl Chir 44 809 (Quoted by Baumgartl, see above)

Pocock G S (1963) Electromyographic Study of the Quadriceps During Resistive Exercise J Amer Phys Ther Ass 43 427-434

Quénu E (1898) Bull et mem Soc de chir de Paris T 24 24 (Quoted by Thiem see below)

Pomaus P (1938) Fall av exstirperad patella vid comminut fraktur Nord med T 16 1187-1188

von Rueff F & Pelzl H (1968) Behandlung von Kniescheibenbruchen mit der Teilpatellektomie Zbl Chir 93 640-643

Scapinelli P (196) Blood Supply of the Human Patella Its Relation to Ischaemic Necrosis after Fracture J Bone Jt Surg 49 B 563-5 0

Schiller S & Mårtenson L (19 0) Traumatisk patellarluxation Foredrag vid Nordisk Ortopedisk Forenings 35 kongres Århus

Schopp A C & Fellhauser C M (1950) Plastic Operation in Fracture of the Patella J Mo med Ass 47 179-183

Schonbauer H P (1955) Trummerbruche der Kniescheibe Arch orthop Unfall Chir 47 66- 71

Schonbauer H P (1959) Bruche der Kniescheibe Ergebn Chir Orthop 4 56-79

Schonbauer H R (1960) Indikation Technik und Wert der Patellektomie Klin Med (Wien) 15 579-581

Seligo W (19 1) Fractures of the Patella Treatment and Results Wiederherstellungschir u Traum 1? 84-10?

Senst W & Nowak, W (1968) Behandlungsergebnisse der Patellafrakturen Dtsch Gesundh wes 3 433-441

Shorbe H B & Dobson C H (19 8) Patellectomy Repair of the Extensor Mechanism J Bone Jt Surg 40 A 1 81-1?84

Smillie I S (19?0) Injuries of the Knee Joint 4th ed E & S Livingstone Ltd Edinburgh

Stener B (1969) Reflex Inhibition of the Quadriceps Elicited from a Subperiostal Tumour of the Femur Acta orthop scand 40 86-91

Struck F (1966) Das Behandlungsproblem der Patellafrakturen mit besonderer Berucksichtigung der Ergebnisse bei der Cerclage und Teilpatellektomie Beitr Orthop Traum 13 329-337

Svantesson G (1971) Hoftbojning eller knäst äckning EMG studier over postoperativ quadricepstraning Foredrag vid Medicinsk Riksstamma Stockholm

Szyszkowitz R & Tscherne H (19?) Patellafrakturen Osteosynthese oder Resektion bei Mehrfragmentbruchen des distalen Drittels Mschr Unfallh ilk 7 393-39

Sorensen K H (1964) The Late Prognosis After Fracture of the Patella Acta orthop scand 34 198- 1

Tessari L (196) *Valutazione a distanza degli esiti di patellectomia* Arch. Ortop (Milano) 75 6 8-637

Te bner E & Schreiner G (1968) Klinik und Therapie der Patellalängsfrakturen (Bericht über 10 Falle) Mschr Unfallh ilk 71 4 6-438

Thiem, C (190) Uber die Grosse der Unfallfolgen bei der blutigen und unblutigen Behandlung einfachen (subcutanen) Querbruche der Kniescheibe Verh. dtsch Ges Chir 34 kongr 3 4-393

Thomson J E M (1935) Comminuted Fractures of the Patella Treatment of Cases Presenting One Large Fragment and Several Small Fragments J Bone Jt Surg 17 431–434

Thomson J E M (1942) Fracture of the Patella Treated by Removal of the Fragments and Plastic Repair of the Tendon A Study of 554 Cases Surg Gynec Obstet 74 860–866

Tiselius P (1969) Studies on Joint Temperature Joint Stiffness and Muscle Weakness in Rheumatoid Arthritis An Experimental and Clinical Investigation Thesis Acta rheum scand Suppl 14

Tornvall G (1963) Assessment of Physical Capabilities with Special Reference to the Evaluation of Maximal Voluntary Isometric Muscle Strength and Maximal Working Capacity Thesis Acta physiol scand Suppl 201

Trendelenburg (1878) Verhandlungen der Deutsch Ges f Chir 1878 (Quoted by Thiem see above)

Tscherne H & Szyszkowitz R (1968) Die stabile Osteosynthese bei Kniescheibenbrüchen Zbl Chir 93 1276–1281

Watson Jones R (1952–1955) Fractures and Joint Injuries 4th ed E & S Livingstone Ltd London

Weber B G (1963) Grundlagen und Möglichkeiten der Zuggurtungs Osteosynthese Chirurg 35 81–86

Weller S & Sammi P (1967) Die partielle Patellektomie als Behandlungsmethode bei Kniescheibenbruchen Mschr Unfallheilk 70 167–172

West F L (1962) End Results of Patellectomy J Bone Jt Surg 44 A 1089–1108

Wiberg G (1941) Roentgenographic and Anatomic Studies on the Femoropatellar Joint Acta orthop scand 12 319–410

Villiger K J (1965) Behandlungsergebnisse bei Patellafrakturen Schweiz med Wschr 18 595–599

von Volkmann R (1868) Virchow und Hirsch Jahresber f 1868 Bd II 364 (Quoted by Thiem see above)

de Vriese B (1909) Bull Acad Méd Belg 23 155 (Quoted by Baumgartl see above)

Wuth L A (1899) Über angeborenen Mangel sowie Herkunft und Zweck der Kniescheibe Langenbecks Arch klin Chir 58 900 (Quoted by Baumgartl see above)

Zadig A (1963) Objektiv matning av muskelkraft med en ny dynamometer Svenska Lak Tidn 60 2937–2953

GUÐMUNDUR GUÐMUNDSSON

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WITH SPECIAL REFERENCE TO THE MOBILE HIP

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FLANDERS BOKTRYCKERI AKTIEBOLAG

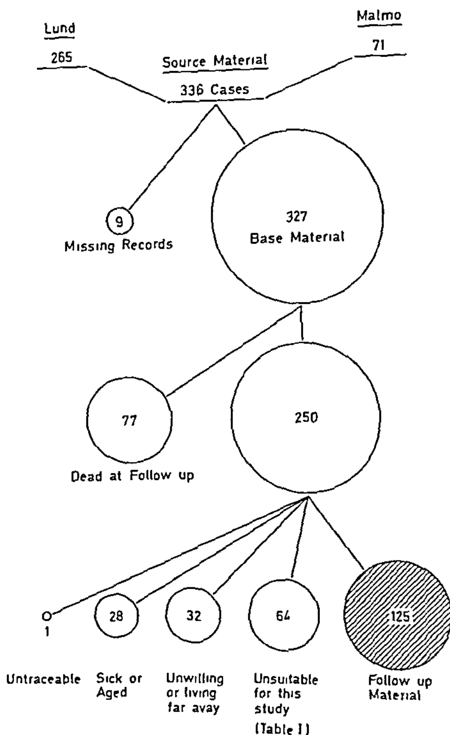


Fig 1 The Material

GÖTEBORG 1972
DERS BOKTRYCKERI AKTIEBOLAG

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From the Department of Orthopaedic Surgery (Head Formerly Prof Gunnar Wiberg Presently Prof Göran C H Bauer) University of Lund Sweden

FUNCTION FOLLOWING ARTHRODESIS FOR COXARTHROSIS

With Special Reference to the Mobile Hip

by

GUÐMUNDUR GUÐMUNDSSON

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CONTENTS

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I INTRODUCTION

Albee introduced the intraarticular arthrodesis of the hip in 1908 Until quite recently this method has maintained a prominent position in the surgical treatment of painful coxarthrosis (Rütt 1969) According to the literature the chief advantage of arthrodesis over other methods is that it gives permanent relief from pain and instability The operation has therefore traditionally been considered well indicated for people doing heavy work or whose occupation involves much walking and/or standing

The aim of the operation in bilateral hip disease has commonly been to achieve not only stability and freedom from pain in the more severely affected joint but at the same time to retard or arrest progress of the disease in the less affected hip The leg on the fused side was thus intended to be used for main support (Watson-Jones 1956 Francillon 1957 Wiberg 1959 Herbert 1960 Mach 1964 Verheugen and Navarre 1964 Becker 1969)

However a fairly extensive search of the literature failed to reveal adequate studies of the support pattern following arthrodesis of the hip or of the fate of the (unoperated) mobile hip compared with its preoperative condition in the two forms of coxarthrosis the primary and secondary

This investigation attempts such a study of 125 cases who had 2 to 22 years previously undergone arthrodesis because of unilateral or bilateral coxarthrosis The investigation comprised a registration of the static support pattern a comparative study of preoperative and follow up radiograms of the mobile hip and a clinical examination The following parameters were studied

a) the extent to which the fused hip was used for static support
b) the incidence rate and degree of radiographic deterioration of the mobile hip
c) the incidence and severity of pain in the mobile hip and the limiting effect of pain on daily activities and working capacity

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c) the incidence and severity of pain in the mobile hip and the limiting effect of pain on daily activities and working capacity

MATERIAL AND METHODS

A Classification of Coxarthrosis

On the basis of preoperative radiograms of the hips the cases were classified as unilateral or bilateral coxarthrosis Radiographic *signs of osteophytes, narrowed joint space or structural changes* were used as criteria of coxarthrosis (Heripret Danielsson and Dymling 1964) Distinction between primary and secondary coxarthrosis was based on the history and radiographic appearance

B Material

The source material comprised 336 cases treated at the Orthopaedic Departments of the Lund University Hospitals in Lund and Malmö Arthrodesis because of coxarthrosis came into regular use *in Lund in 1945 and in Malmö in 1952 All cases operated through* 1965 were included in the source material It consisted of 195 females and 141 males a ratio of 1 3/1 The average age at operation was 55 years the same for both sexes Over half of the cases were 50 to 65 years old at operation (Fig 1)

1 Base Material

Hospital records of 9 cases were missing or incomplete This reduced the number of cases to 327 (Base Material) on which adequate data were available From the records and radiographic descriptions of these cases it was found that at the time of operation 177 had unilateral and 150 bilateral coxarthrosis The distribution between primary and secondary coxarthrosis was 191 and 136 cases respectively

2 Selection of the Probands

Only cases filling the following requirements were accepted

a) the mobile hip must not have been rendered unfit for radiographic assessment by a high *congenital* dislocation or some intraarticular operation

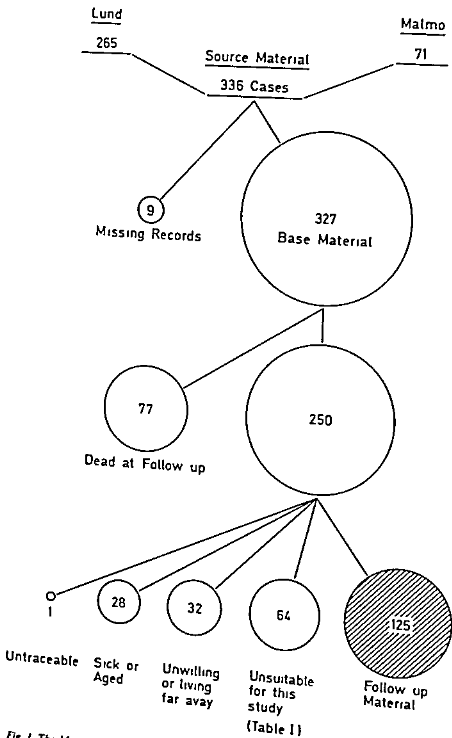


Fig 1 The Material

b) radiographic and/or clinical signs of firm union in the operated hip,

c) available preoperative radiograms of the mobile hip or adequate radiographic and clinical descriptions of the preoperative state

d) availability of the case at the time of follow-up examination

Potential probands were contacted by letter and/or telephone All those willing and able to participate were examined In all 159 cases were examined but 34 of these failed to meet the above requirements (non-union 28, arthroplasty of mobile hip 4 high congenital dislocation of mobile hip 2) A further 30 were excluded because of similar findings in the records and radiograms (Table I)

Table I Cases found unsuitable for follow-up

Cause	Number
Mobile Hip	
Arthroplasty or Resection	15
High Congenital Dislocation	3
Operated Hip	
Resection (Girdlestone)	4
Non-union	41
Femoral Amputation	1
Total	64

In 12 cases the radiograms obtained at follow-up were inconclusive i e lacking in definite radiographic evidence of solid union All these hips were free from pain and clinically firmly united Although osseous union may not always have been complete all 12 cases were accepted as probands

Of 16 cases in which preoperative radiograms of the mobile hip were not available 10 were free from signs of arthrosis at follow-up The remaining 6 had minimal changes i e only slightly reduced joint space and/or marginal osteophytes The interval between the operation and follow-up of these 6 cases was 15 to 22 years It was therefore considered reasonably certain that these hips had been

normal at the time of operation These cases were accepted as probands

Four cases with bilateral disease at the time of operation were accepted as probands despite unavailability of preoperative radiograms of the mobile hip The hospital records of all 4 cases contained adequate descriptions of the original radiograms

3 Description of Probands

Seventy seven of the 125 probands were females and 48 males a ratio of 1 6/1 At operation 75 probands had unilateral and 50 bilateral coxarthrosis and 61 had primary and 64 secondary coxarthrosis in the hip that was fused

The distribution within the different subgroups of the material was largely the same in the Base Material as in the Follow-up Material (Fig 2) The only appreciable difference was a relative loss of males with primary coxarthrosis and a corresponding gain of females with secondary coxarthrosis

Of the 77 cases dead att follow-up 42 were males Two thirds of the 77 cases had had primary coxarthrosis

a Unilateral Coxarthrosis

Of the 75 cases operated for unilateral coxarthrosis 50 had secondary and 25 primary coxarthrosis The diagnoses in the secondary cases are given in Table II There were 53 females and 22 males

Table II Etiology in 50 Probands operated for Unilateral Secondary Coxarthrosis

Etiology	Number
Developmental Disturbance	
Dysplasia	9
Congenital Dislocation	6
Epiphysiolysis	2
M. Perthes	3
Coxa [illegible]	1
	21
Inflammation	
Septic Coxitis	9
Tuberculous Coxitis	7
Osteomyelitis	3
Rheumatoid Arthritis	1
	16
Trauma	
Fracture of Femoral Neck	11
Total	50

b) radiographic and/or clinical signs of firm union in the operated hip

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3 Description of Probands

Seventy seven of the 125 probands were females and 48 males a ratio of 1 6/1 At operation 75 probands had unilateral and 50 bilateral coxarthrosis and 61 had primary and 64 secondary coxarthrosis in the hip that was fused

The distribution within the different subgroups of the material was largely the same in the Base Material as in the Follow-up Material (Fig 2) The only appreciable difference was a relative loss of males with primary coxarthrosis and a corresponding gain of females with secondary coxarthrosis

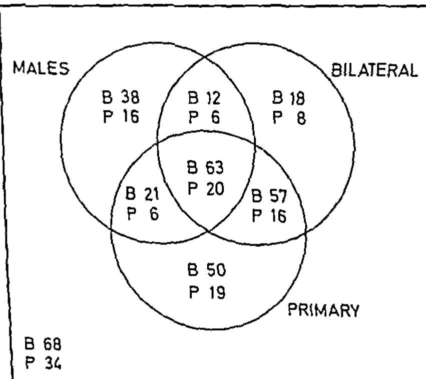
Of the 77 cases dead att follow-up 42 were males Two thirds of the 77 cases had had primary coxarthrosis

a Unilateral Coxarthrosis

Of the 75 cases operated for unilateral coxarthrosis 50 had secondary and 25 primary coxarthrosis The diagnoses in the secondary cases are given in Table II There were 53 females and 22 males

T ble II Etiology in 50 Proband Op ted I
Unila ral Seconda y Coxa th i

Eti logy	Numb
Dev lopmen l Di se se	
Dyspla ia	9
Congenital Di loc tio	6
Epiphy i ly i	2
Mb P th	3
C xa valg hli	1
	21
I flamm on	
Septi Coxiti	9
T ber ulou Co iti	7
O eom l i	1
Rheuma toid A h iti	1
	18
T m	
F tu f F mo al Neck	11
T tal	50



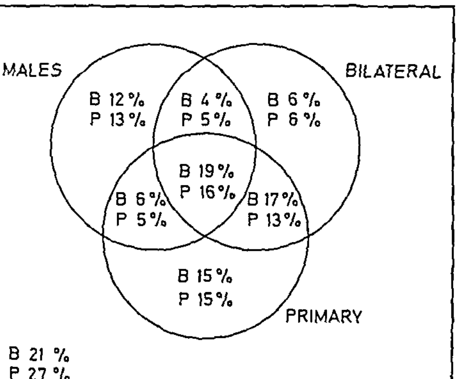


Fig 2 *Distribution of Material in Terms of Sex Laterality and Type of Coxarthrosis*

A *Base Material (B 327 Cases) and Probands (P 125 Cases) according to Sex Unilateral or Bilateral and Type of Coxarthrosis (Primary or Secondary)*

B *Percentage of the total Number of Cases of Base Material (B) and Probands (P) within each of the eight subgroups*

b Bilateral Coxarthrosis

Of the 50 bilateral cases 36 had primary and 14 secondary coxarthrosis (Table III) There were 24 females and 26 males

Table III Etiology in 14 Probands operated for Bilateral Secondary Coxarthrosis

Etiology	Type of Arthrosis	Number
Fused Hip	Mobile Hip	
BOTH HIPS		
Developmental Disturbances		
Dysplasia	Same	4
Congenital Dislocation		1
Coxa vara		1
Inflammation		
Rheumatoid Arthritis		4
ONE HIP		
Developmental Disturbances		
Epiphysiolysis	Primary	1
Mb Perthes		1
Trauma		
Fracture of Femoral Neck		1
Fracure of Acetabulum		1
	Total	14

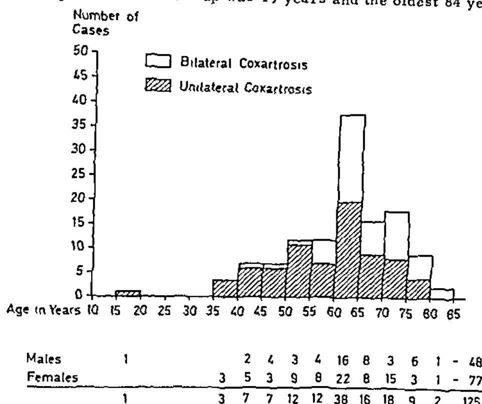
c Age at Operation

More than half of the probands were 50 to 65 years old at the time of operation The average age was 52 years and was the same in both sexes The average age of those with primary coxarthrosis was 8 years higher than of those with secondary coxarthrosis or 56 and 48 years respectively The youngest proband at operation was 17 years and the oldest 74 years

d Age at Follow up

Over half of the probands were 60 to 75 years old The average age was 61 years (Fig 3) and was the same in both sexes The

average age of the probands with primary coxarthrosis, mainly bilateral was 66 years while the corresponding age of the probands with secondary coxarthrosis, mainly *unilateral, was 57 years The* youngest proband at follow-up was 19 years and the oldest 84 years



Males	1		2	4	3	4	16	8	3	6	1	- 48
Females		3	5	3	9	8	22	8	15	3	1	- 77
	1	3	7	7	12	12	38	16	18	9	2	125

Fig 3 Age Distribution at Follow up

e Follow-up Period

The interval between operation and the follow-up examination was 2 to 22 years *For 102 of the probands it was at least 5 years* The average interval was 10 years and was the same for females and males and for unilateral and bilateral coxarthrosis

f Length of Hospitalization

Four probands were referred to their local hospitals a few days postoperatively for further convalescence The rest were discharged as soon as they could walk and manage at home usually with domestic *help*

Of the remaining probands, 109 operated upon once spent on the average 3 3 months (range 1-7 months) *in hospital* 9 *operated upon* twice 5 7 months (range 2 5-11 months) and the remaining 3 operated upon three or four times 8 months (range 4 5-10 months)

The above figures include only operations for securing fusion i e no osteotomies, extraction of nails or sequestrectomies etc

C Methods

1 Follow up Procedure

The follow-up procedure was carried out from February 1968 to February 1969 and comprised a registration of the mode of static support radiographic and clinical examinations

The whole procedure took 2 5 3 hours As a rule the static support test was carried out first and was performed by an assistant at the Balance Laboratory of the Department of Otolaryngology in Lund Thereafter the radiographic examination was performed at the Department of Radiology Section II which serves the Orthopaedic Department The radiographic examination was followed immediately by the clinical examination which was always made by the author

2 Static Support Test

a Purpose

The purpose of the test was to find out

i) which leg was preferred under static conditions in unilateral and bilateral coxarthrosis

ii) whether this support pattern was influenced by the position of the fused hip and/or discrepancy in relative leg length

iii) the number of shifts of leg most loaded and to compare this with what may be considered normal in healthy individuals

iiii) whether the probands were able to load both legs equally and whether the ipsilateral and contralateral leg could be used for supporting leg (> 60% of body weight) alternately for a short period of time

iiiii) the support pattern during Romberg s test and compare this with the preferred pattern in the first part of the test

Of further interest was a comparison of the opinion of the probands and the results of the test as regards which leg was generally loaded with more than half of body weight

b Equipment

At the Balance Laboratory of the Otolaryngological Department certain equipment was used for registration of Romberg s test (Henriksson Johansson Olsson and Östlund 1967)

After slight modifications this equipment proved well suited for studying the pattern of static weight distribution It consisted of a platform (109 x 90 cm height 21 5 cm) in two sections, enclosing two electric scales (Bofors Co Sweden), working on strain gauge principles (Fig 4) The scales, one for each foot contained two strain gauges each The platform and scales were movable easily adjustable to individual requirements and indistinguishable from quite firm footing

A voltage proportional to the weight on each scale was registered on an inkwriter (Mingograf) calibrated so that 100% of body weight gave identical amplitude i e equal deviation from the base line which represented even loading on both scales

By recording the difference in voltage between the scales on one of the channels of the inkwriter (Channel 1) the difference in load on the scales was measured On Channel 2 the algebraic values for deviations (deviations toward the right minus deviations toward the left or vice versa) were electrically integrated and recorded (Fig 4)

c Procedure

The static support test was developed by the author The test lasted for exactly 20 minutes With calibration and various delays the actual measuring time was often 5 to 10 minutes longer

After adjusting the distance between the scales to the comfort of the proband the scales were calibrated The *probands were not* informed in advance of the various parts of the test To begin with they were asked to stand in their habitual manner as when waiting for a bus or standing in a queue All other instructions were given at appropriate intervals

i) Preferred mode of support was registered for two 5 minute periods interrupted by 5 minutes of equal support on both legs (vide infra) This interruption had a dual purpose first to find whether the probands returned to the same mode of support and then to find whether the frequency of shifts increased in the latter period

ii) During a 5 minute period the *probands* were asked to load both legs as equally as possible They were routinely reminded of this about once every minute

iii) In direct continuation of the above 15 *minutes* the probands were instructed first to load the mobile leg for 2 minutes in a relaxed manner to relieve the fused leg and then vice versa by loading the fused leg

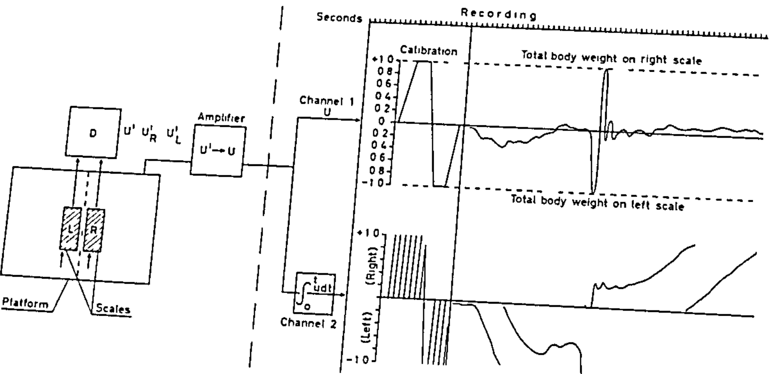


Fig 4 Recording of Static Support Pattern

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a line representing the pelvic horizontal (vide infra) and a line drawn along the inner contour of the proximal femoral shaft

Table IV Assessment of Radiographic Severity

(Fr Heripret Danielsson and Dymling 1964)

Severity		Index
Osteophytes		
	None	0
	Visible on one pole of the joint	1
	Visible on both poles	2
	Bulky on both poles	3
Joint Space		
	Normal	0
	Narrowed but larger than half normal width	1
	Smaller than half normal width	2
	Effaced over more than half femoral contour	3
Structure		
	Normal	0
	Hyperdensity or cysts in caput or acetabulum	1
	Hyperdensity or cysts in caput and in acetabulum	2
	Grossly destroyed	3
Associated anomalies		
	None	0
	Double Floor	1

Radiograms of the lumbar spine and knees had not always been taken before the operation Comparison with the radiograms obtained at follow up was therefore rarely possible but these radiograms demonstrated arthrotic changes in other adjoining joints

a Procedure

The hip joint was always fused in a varying degree of flexion If ab and adduction is determined radiographically with the central ray directed on the symphysis the flexed position will tend to increase the angle of abduction measured on the film and decrease that of adduction

iiii) Finally, Romberg's test was carried out, the probands being instructed to stand with their eyes closed for as long as possible up to 1 minute

All stages of the test were done successively This proved fairly strenuous for some of the probands None of the probands expressed difficulty in assuming or maintaining their habitual standing position Two probands were allowed to use a cane to keep their balance Eleven probands were tested twice at 3 to 11 month intervals No appreciable difference was found between the results of the two tests

d Calculation

The tracings on Channel 1 (Fig 4) represented the difference in loading of the two scales expressed as body weight (P) The tracings on Channel 2 represented the integrated loading difference expressed as body weight multiplied by time The speed of integration was adjusted so that during calibration with total body weight on one scale the integrator was filled in one second, each stroke representing "1 body weight" per second (Fig 4)

After each period of the test, the difference between the number of strokes on both sides of the base line was divided by the number of seconds in that period The result gave a constant (k) by which the average loading on each of the two scales could be calculated from the expression $P = \frac{1 + k}{2}$ for the leg supporting the major part of bodyweight and $P = \frac{1 - k}{2}$ for the other during the period

To avoid repitition and misunderstanding it was found convenient to express average loading of the fused leg as a percentage of bodyweight Thus, if e g the average weight supported by the mobile leg during a certain period was 65% of bodyweight, it was expressed as 35% f l (fused leg)

3 Radiographic Examination

At follow-up all probands were subjected to radiographic examination af the pelvis hips lumbar spine and knees The aims of the radiographic examination were primarily

a) to assess radiographic signs of coxarthrosis as compared with those in preoperative radiograms The severity of the changes was classified according to a numerical index (Table IV)

b) to determine the degree of ab- and adduction of the fused hip by

The neutral angle according to Weinreich (1960) is that in which the midpoint of the hip knee and ankle joint are joined by a vertical line representing symmetrical weight distribution between both legs In this mechanical midposition which is equivalent to a distance of about 18 cm between the midpoints of the two ankle joints the long axis of the femur is adducted toward the midline

Lindahl (1965) chose a basic position with the feet together In this position the neutral angle is formed by the pelvic horizontal and the leg (femur) The angle varies with the width of the pelvis and the leg length This factor must be taken into account to secure uniform measurements The neutral angle was calculated from the distance between the femoral heads on the radiograms and the length of the normal leg measured clinically

ii) Calculation of the Neutral Angle The neutral angle was calculated from the expression $\cos \alpha = \frac{P}{2L}$ P denoting the distance between the femoral heads and L the length of the normal (mobile) leg

When the angle of the fused hip as measured on the radiograms was smaller than the neutral angle the difference denoted the degree of adduction in the fused hip and conversely when greater the degree of abduction This method was employed throughout the investigation It was tested by calculating the neutral angle in 10 normal persons and was found to deviate by at most three degrees from the angle measured directly on their radiograms

4 Clinical Examination

The aim of the clinical examination was to assess and record

a) the range of motion and degree of pain in the mobile hip

b) the degree of flexion in the fused hip and

c) the state of the lumbar spine and knees

Further notes were made of the probands accounts of their working capacity

The physical examination was carried out in a conventional manner (Method of Measuring and Recording American Academy of Orthopaedic Surgeons 1965)

Published methods for assessment of pain (Judet & Judet 1952 Shepard 1954 Stinchfield 1957 Danielsson 1964) use a numerical index from (0) 1 to (5) 6 In the author s opinion hip pain was best assessed by its restrictive effects on daily activities and work or sleep and by the use of analgesics rather than by noting starting

In most cases the angle formed by the fused leg and the table could be easily eliminated by extension (lordosis) of the lumbar spine However, owing to stiffness of the back this was not always complete This source of error was eliminated by the following procedure (focal distance 150 cm)

First Radiogram With the proband supine on AP projection was taken with vertical direction of the rays, centered immediately above the symphysis Film size 30 x 40 cm covering the whole pelvis and upper part of both femoral shafts A metal measuring scale was placed under the proband i e between him and a mattress covering the table

Second Radiogram The floating table top was moved laterally about 10 cm to center the beam over the fused hip Film size 30 x 40 cm, was placed longitudinally, covering the hip and at least 10 cm of the femoral shaft The metal scale was in the same position as in the first radiogram

Conventional frontal and lateral projections of the mobile hip, knees and lumbar spine were obtained

b Measurement of the Frontal Position of the Fused Hip

The measurement was made as follows
On the first radiogram a reference line was drawn through the lower ranges of the sacro-iliac joints On the second radiogram a line was drawn along the inner contour of the upper femoral shaft This radiogram was then superimposed on the first using the metal scale as a landmark The reference line of the first radiogram was then traced on the second The angle thus formed by the two lines gave the frontal angle of the fused hip

i) The Neutral Position In clinical practice the frontal position and motion in ab- and adduction have traditionally been measured from a zero position in which the anterior contour of the thigh forms a right angle with the superior-anterior iliac spines

This position actually represents a considerable degree of abduction in the hip owing to the inclination of the femur toward the median plane In the upright position it will correspond to an abduction of the hip of nearly 10 degrees from the standing position (Charnley 1953)

The neutral angle according to Weinreich (1960) is that in which the midpoint of the hip knee and ankle joint are joined by a vertical line representing symmetrical weight distribution between both legs In this mechanical midposition which is equivalent to a distance of about 18 cm between the midpoints of the two ankle joints the long axis of the femur is adducted toward the midline

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pain pain when walking etc Assessment was therefore restricted to the following four grades

Grade 0 no pain

Grade 1 slight or occasional pain rarely interfering with work or daily activities often relieved by rest and seldom requiring analgesics ,

Grade 3 moderate pain that may periodically interfere with work or activities and requiring frequent use of analgesics

Grade 5 severe or disabling pain curbing activities and work disturbing sleep or so severe that the proband had been granted a disability pension

Functional capacity after the operation was assessed by grading some daily activities and working capacity The grading was based on Shepard s (1954) method but slightly shortened Thus e g limp and difficulty in putting on socks and shoes were omitted as these were natural consequences of a successful arthrodesis and were present in all cases (Table XX)

5 Statistical Methods[1)]

Only well known statistical techniques were used (Blom G 1969) mainly the chi-square test In a few cases the sign test and Student s t-test were applied

Statistical significance was described as follows

P>0 05	= not significant
0 05 > P>0 01	= almost significant
0 01 > P>0 001	= significant
0 001 > P	= highly significant

1) Data treated statistically by civil engineer Tore Persson Department of Mathematical Statistics University of Lund

A Static Support Test

1 Preferred Mode of Support in Standing

a Support Pattern

Henriksson et al (1967) who used the same equipment as that used in this investigation (cf p 13) found that normal persons seemed to deviate on the average 6 - 7% of body weight in the lateral direction Therefore deviations from the base line of up to 10% of body weight were in the present investigation taken to signify equal weight distribution on both legs and henceforth termed equal support (40% -60% f 1) Accordingly an average load of > 60% of body weight on either leg during this part (10 min) of the test was taken as a sign of a clear preference for the leg in question (supporting leg)

The support pattern obtained with the above differentiation is illustrated in Fig 5 There were two groups representing an average loading of > 60% of body weight on one leg and a middle group with equal loading on both The mobile leg was used as a supporting leg three times as often as the fused leg

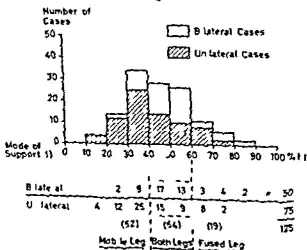


Fig 5 Static Support Pattern Preferred Mode of Support during 10 Minutes

The difference in support pattern between the unilateral and bilateral cases is also illustrated in Fig 5 The main difference was that in two thirds of the bilateral cases both legs were loaded equally, whereas in over half of the unilateral cases there was a clear preference for the mobile leg

One hundred and twelve of the probands showed the same support pattern in both 5 minute periods In the 13 probands who did not, the mean value of both periods placed all but one within the group with equal support

Comments

The opinion of the probands as to which leg was generally loaded with more than half of body weight (main support) was compared to the results of the preferred support pattern The base line (50% of body weight on each leg) divided the material in two parts (Fig 5) two thirds (84) loading the mobile leg with more than half of body weight and one third (41) the fused leg Six probands had even loading on both legs These were divided equally among the two groups The result of the test bore a close resemblance to the opinion of the probands as 87 (70%) thought they generally loaded the mobile leg with more than half of body weight during standing 29 (23%) the fused leg an 9 (7%) both legs equally

The opinion of the probands regarding the leg mostly used for support during standing was in agreement with the results of the test in over 75% of the cases Most of the 32 probands whose opinion differed from the results of the test displayed no clear preference for either leg (40% - 60% f 1)

Hohman (1962) studied the support pattern in 75 cases with hip arthrodesis by letting them stand on two scales for 15 minutes He found that the fused leg was loaded in the following manner up to 1/4 of body weight 19% 1/4 - 1/2 of b w 51% and over half of body weight 30% The corresponding figures in the present material were up to 1/4 of b w 7% 1/4 - 1/2 of b w 60% and over half of body weight 33%, and thus in good agreement with those given by Hohman Further both investigations revealed that support by the fused leg and fairly equal support by both legs was more common than what is given in other reports based on clinical observations but without measuring devices (Table V)

Table V Preferred Mode of Support in Standing
Earlier Studies compared with the Present

Author	Number of Cases	Support Pattern		
		Fused Leg	Mobile Leg	Both Legs
Hohman (1962)	75	22 (30%)	53 (70%)	
Hauge (1963)	75	10 (13%)	60 (80%)	5 (7%)
Mach (1964)	68	9 (13%)	59 (87%)	
Seevald and Debrunner (1964)	60	2 (3%)	52 (87%)	6 (10%)
Lindahl (1965)	35	6 (17%)	26 (74%)	3 (9%)
Demigneux (1968)	59	6 (10%)	47 (80%)	6 (10%)
Present Study	125	41 (33%)	84 (67%)	

b Support Pattern in Relation to Frontal Position of Fused Hip

There was a difference in support pattern between probands with adduction and those with abduction of the fused hip In the former the fused leg was more often used for main support than in the latter Of 38 probands with adduction of the fused hip 16 used the fused leg for main support compared with 25 of the 87 probands with abduction

Cases with from 5 degrees of adduction to 5 degrees of abduction in the fused hip were pooled and the group was called neutral (Table VI) There were 58 cases with neutral position 12 with adduction (range 6 12) and 55 cases with abduction of the fused hip (range 6 -25) The distribution of the 41 cases which used the fused leg for main support within the adduction neutral and abduction groups was such that they constituted about 1/2 1/3 and 1/4 of the cases in each group The relative proportions within the three groups of the 19 cases which used the fused leg as supporting leg (> 60% f l) was roughly 1/4 1/5 and 1/18 respectively

Loading of the fused leg thus seemed to be *facilitated* by the neutral or adducted position

The difference in support pattern between the unilateral and bilateral cases is also illustrated in Fig 5 The main difference was that in two thirds of the bilateral cases both legs were loaded equally, whereas in over half of the unilateral cases there was a clear preference for the mobile leg

One hundred and twelve of the probands showed the same support pattern in both 5 minute periods In the 13 probands who did not, the mean value of both periods placed all but one within the group with equal support

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Comments

According to Seevald and Debrunner (1964) one of the reasons why most of their cases (Table V) loaded the mobile leg was excessive flexion in the fused hip In the present material however large flexion angles did not seem to have any adverse effect on loading of the fused leg

d Frequency of Shifting Leg of Main Support

The normal energy saving static posture requires that body weight can be shifted freely (cf p 31) from one leg to the other The number of shifts during the static support test was shown by the tracings of the inkwriter (Fig 4) In the following a shift means that more than half of body weight was shifted from one leg to the other for at least 15 seconds

The frequency of shifting was found to vary considerably with the support pattern Those showing preference for one leg shifted more often in the early 5 minute period whereas those with equal support displayed increase in the number of shifts in the latter half of the test period Further the average total frequency of shifts was highest for those with equal support (Table VIII)

Table VIII Preferred Mode of Support in Standing versus Number of Shifts of Supporting Leg

Support Pattern	Number of Shifts		Total	Average Number of Shifts
	First 5 min Period	*Second 5 min* Period		
<40% f 1	22	15	37 52	0 71
40%-60% f 1	69	86	155 54	2 9
>60% f 1	18	6	24 19	1 3
Total	109	107	216 125	1 7
Average Number of Shifts	0 9	0 9		

Comments

Smith (1953) observed 250 persons standing in bus queues and found that most of body weight was shifted among the legs on the average every 30 seconds He found asymmetrical standing i e what he considered nearly the whole weight of the body supported by one leg to

Table VI Preferred Mode of Support in Standing versus Frontal Position of Fused Hip

Support Pattern	Adduction		Neutral		Abduction		Total	Mean Support Fused Leg
	>10	6 -10	0 -5	0 -5	6 -10	>10		
<40% f l	1	2	12	16	11	10	52 (42%)	32% f l
40%-60% f l	2	4	8	9	20	11	54 (43%)	49% f l
>60% f l	1	2	6	7	3		19 (15%)	70% f l
Total	4	8	26	32	34	21	125 (100%)	44% f l
Number of Probands with Main Support by Fused Leg	3	4	9	10	10	5	41 (33%)	
Mean Support f l	65%	67%	63%	67%	61%	56%		63% f l

c Support Pattern in Relation to Sagittal Position of Fused Hip

The sagittal position of the fused hip varied from 15 to 55 degrees of flexion The material was divided into three groups with regard to the angle of flexion There were 39 probands with fairly small angles (range 15 -29), 60 with moderate (range 30 -39) and 26 with large angles of flexion (range 40 -55)

The 19 probands who showed a clear preference for the fused leg were distributed among the three groups, roughly making 1/6, 1/9 and 1/4 of the cases in each The corresponding proportions for the 41 probands with main support by the fused leg was 2/6, 2/7 and 2/5 (Table VII)

Table VII Preferred Mode of Support in Standing versus Degree of Flexion of Fused Hip

Support Pattern	Degree of Flexion					Total
	10 -19	20 -29	30 -39	40 -49	≥50	
<407 f l		14	28	9	1	52
40%-60% f l	2	17	25	9	1	54
>60% f l		6	7	5	1	19
Total	2	37	60	23	3	125
Number of Prob with Main Supp by Fused Leg	14		16	11		41
Mean Support f l	627 f l		62% f l	65% f l		63% f l

Comments

According to *Seevald and Debrunner (1964) one of the reasons why* most of their cases (Table V) loaded the mobile leg was excessive flexion in the fused hip In the present material however large flexion angles did not seem to have any adverse effect on loading of the fused leg

d Frequency of Shifting Leg of Main Support

The normal energy saving static posture requires that body weight can be shifted freely (cf p 31) from one leg to the other The number of shifts during the static support test was shown by the tracings of the inkwriter (Fig 4) In the following a shift means that more than half of body weight was shifted from one leg to the other for at least 15 seconds

The frequency of shifting was found to vary considerably with the support pattern Those showing preference for one leg shifted more often in the early 5 minute period whereas those with equal support displayed increase in the number of shifts in the latter half of the test period Further the average total frequency of shifts was highest for those with equal support (Table VIII)

Table VIII Preferred Mode of Support in Standing versus Number of Shifts of Supporting Leg

Support Pattern	Number of Shifts		Total	Average Number of Shifts
	First 5 min Period	Second 5 min Period		
<40% f 1	22	15	37 52	0 71
40%-60% f 1	69	86	155 54	2 9
>60% f 1	18	6	24 19	1 3
Total	109	107	216 125	1 7
Average Number of Shifts	0 9	0 9		

Comments

Smith (1953) observed 250 persons standing in bus queues and found that most of body weight was *shifted* among the legs on the average every 30 seconds He found asymmetrical standing i e what he considered nearly the whole weight of the body supported by one leg to

be about four times as frequent as symmetrical standing

Hohman (1962) studied the preferred manner of support of 75 probands with arthrodesis of the hip in standing during 15 minutes He found that during the first few minutes the body weight was frequently shifted from one leg to the other, as a rule followed by a certain stability with slow variation A change of supporting leg was rarely noted thereafter

The remarkably small number of shifts during the static support test compared with observations in normal persons, may be an indication of the restrictive effect of the fusion in this respect The lower frequency of shifts among those mainly loading one leg suggests that the support pattern was deeply rooted and uniform as shifts were less frequent in the second half of the test Thus the two to threefold frequency of shifts among the probands who displayed equal support *may be explained by the fact that they had more symptoms in the mobile* hip and therefore were less comfortable in any position (Table IX)

e Support Pattern in Relation to Leg Length Discrepancy

One hundred and seven of the probands had a discrepancy in relative leg length 101 shortening and 6 lengthening of the fused leg In 18 cases no difference was found

The distribution according to support pattern and frontal position of the fused hip of the 52 cases with 2 cm or more of uncompensated shortening of the fused leg during the static support test was largely the same as that of the material as a whole (Table VI) Thus 22 *showed equal support and the rest* preferred support by one leg (19 the mobile and 11 the fused leg) Still the adducted or neutral position and support by the fused leg were somewhat more common in the 52 cases than in the rest of the material

Equal support was on the other hand less common among the 21 cases with 3 cm or more *shortening Fifteen of these* had preferred support by one leg (9 the mobile and 6 the fused leg)

Of the 6 cases with relative lengthening of the fused leg from 1 to 4 cm (average, 2 cm) 2 had compensatory heel raises on the mobile side Four had equal loading on both legs and 2 preferred the mobile leg

Eighteen cases had no measureable discrepancy in leg length Eight loaded both legs equally 7 preferred the mobile and 3 the fused leg

Table IX Preferred Mode of Support in Standing versus Increase in Radiographic Index and Pain in Mobile Hip

Support Pattern	Increase in Radiogr Index											Total	Average Increase In Radiogr Index	Number	Pain Index	Number
	0	1	2	3	4	5	6	7	8	9	10					
<40% f 1	33	8	6	1	1	1	2					52	0 8	19	1 0	24
40%-60% f 1	14	18	9	4	3	4	1		1			54	1 7	40	1 4	31
>60% f 1	10	1	2	3			2	1				19	1 7	9	1 7	13
T o t a l	57	68										125	1 4	68	1 3	68

be about four times as frequent as symmetrical standing

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The remarkably small number of shifts during the static support test, compared with observations in normal persons may be an indication of the restrictive effect of the fusion in this respect The lower frequency of shifts among those mainly loading one leg suggests that the support pattern was deeply rooted and uniform as shifts were less frequent in the second half of the test Thus the two to threefold frequency of shifts among the probands who displayed equal support, may be explained by the fact that they had more symptoms in the mobile hip and therefore were less comfortable in any position (Table IX)

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Eighteen cases had no measureable discrepancy in leg length Eight loaded both legs equally 7 preferred the mobile and 3 the fused leg

2 Instructed Modes of Support in Standing

a Equal Support by Both Legs

Eighty nine (71%) of the probands managed equal support for a period of 5 minutes Of the 36 probands who failed 24 retained their preference for loading the same leg as they had in the first part of the test 18 of them the mobile leg and 6 the fused leg Of the remaining 12 probands 8 who in the first part of the static support test showed equal support had changed to support by one leg 7 by the mobile leg and 1 by the fused leg Of the remaining 4 cases 3 had changed from support by the mobile leg to the fused and 1 vice versa

Comments

It is difficult to explain why these 36 cases could not manage equal support for e g leg length discrepancy extreme positions of the fused hip or changes in the mobile hip or other joints were not more common in this group than in the rest of the material

b Support by Fused Leg

One hundred and eleven (89%) of the probands could use the fused leg for support (> 60% of b w) during a period of 2 minutes This invariably involved more or less leaning toward the fused side and forwards

Fourteen probands could not load the fused leg to such an extent average 54% f l (range 41%-60% f l) Ten had preferred the mobile leg in the former part of the static support test Their support pattern thus appeared to be confined to one mode Possible contributary causes in 8 of the latter were as follows 5 had a combined abduction of the fused hip and severe arthrosis of the mobile hip with little or no frontal motion and 3 had pain in the ipsilateral knee when standing for any length of time

c Support by the Mobile Leg

One hundred and sixteen (93%) of the probands could use the mobile leg for support for two minutes Of the 9 probands who could not 5 had equal support in the first part of the static support test and 3 had preferred the fused leg The remaining one of these 9 was the oldest proband in the material an 84 year old woman with pain in the mobile

Comments

Relative shortening of the fused leg was slightly more common in the 41 cases with main support by the fused leg than in the rest of the material Twenty of the 41 cases had an uncompensated shortening of 2 cm or more compared with 32 of the remaining 84

Large, uncompensated shortenings (≥ 3 cm) were most common among the 19 cases with preference for the fused leg Thus, one third (6) of these compared with one sixth (9) of those preferring the mobile leg and only ninth (6) of those with equal support had such large shortening

Many of the probands had been reluctant to use a heel raise to compensate shortening of the fused leg Only 46 of the 101 cases used a heel raise more or less regularly Such compensation was seldom used if the shortening was less than 3 cm, but even 13 of the 41 probands with a shortening of 3 cm or more never used one Of the 46 probands using a heel raise 9 used it only intermittently or during working hours

Practically all of the probands with a shortening of 2 cm or more had been prescribed a heel raise after operation However, half of them had stopped using it because they felt that the fused leg had become too long and was more "in the way", often causing them to stumble or fall

f Support Pattern versus Radiographic Deterioration and Pain

The incidence and amount of radiographic deterioration and pain in the mobile hip was largest among those of the probands who preferred equal support or support by the fused leg (Table IX) Roughly two thirds of the latter showed increase in radiographic severity compared with one third of those who preferred the mobile leg The difference was significant As regards pain three fifths of the former and nearly half of the latter had pain in the mobile hip

The degree of deterioration and pain was thus least among the 52 probands who preferred the mobile leg for support This was in good agreement with the views of many of the probands who stated that as symptoms increased in the mobile hip more of their body weights had been transferred to the fused side

3 Discussion

The mode of standing and the forces acting on the hip joint under normal and pathologic conditions have been investigated by a number of authors (Walmsley 1933 Akerblom 1948 Felton and Wright 1949 Smith 1953 Schede 1956 Fürmaier 1959 Weinreich 1960 Denham 1959 Hohman 1962 Jonsson and Steen 1962 Casuccio 1964 Rydell 1966 Henriksson et al 1967) The consensus of opinion is that if the standing position is to be maintained for any length of time body weight is not supported equally by both legs Instead the posture of at ease is adopted i e the bulk of body weight resting on one leg with Trendelburg s sign positive In this posture the large joints of the weight bearing extremity hip and knee are stabilized in the extended position by the strong ligaments reinforcing their joint capsules Muscle activity is then largely confined to the interplay of antagonists for keeping balance further facilitated by the passive counterweight of the unloaded leg (Fig 6 b) This is the energy saving standing posture adopted during longer periods in which body weight is alternately shifted from one leg to the other whereas maintaining balance on both legs requires considerably more muscle activity A requirement for adopting and maintaining the former posture is that the line of body weight must pass through the center of the supporting foot dividing the body into two balanced halves A necessary condition for this is that the line of body weight passes medially to the supporting hip joint which in turn involves lateral translation of the pelvis toward the supporting side along with lowering of the pelvis toward the unloaded side The only other way of supporting body weight mainly by one leg is that with Trendelenburg s sign negative which involves elevation of the pelvis on the unloaded side abduction of the supporting hip joint and lateral translation of the pelvis along with a lumbar scoliosis convex toward the same side (Fig 6 c) The posture with Trendelenburg s sign negative implies a continuous muscular effort and is therefore not adopted for longer periods in daily life only when walking

After arthrodesis of the hip standing on the fused leg can no longer be facilitated by translation of the pelvis toward the loaded side by adducting the supporting hip There are two possible ways by which the arthrodesed person can load the operated side with more than half of his body weight In order to establish balance he can either lean the upper part of the body toward the side of support (Fig 6 d) or by

hip and suffering from vertigo, which might perhaps explain the inconclusive results of the test as, in this part she had 46% f l but 35% f l in the first part of the test Of the 9 probands 6 had severe changes in the mobile hip with little or no frontal motion and, with pain (5 cases)

d Romberg s Test

Finally, Romberg s test was carried out Most of the probands managed to stand with their eyes closed for about 35-40 seconds or more Ninety of the probands displayed the same support pattern as they did in the first part of the test

The support pattern was thus found to have almost the same features as that of the first part of the static support test The main difference was that equal support by both legs was slightly more common in this part Thus 22 probands who preferred one leg in the first part had changed to equal support whereas 9 probands with equal support in the first part had changed to support (<40% f l) by the mobile leg and 1 to the fused leg Thus the final support pattern in Romberg s test was <40% f l = 45 40% - 60% f l = 66 and >60% f l = 14 probands

Comments

The results of the second part of the static support test showed that in general the probands were able to load whichever leg they chose when a conscious effort was made to do so However, a few probands did not seem to have much choice in this regard due to stiffness and/or pain in the mobile hip For many of the probands support by the fused leg for 2 minutes proved exceedingly fatiguing and many expressed relief when this part of the test was over

As a rule support by the mobile leg was obviously better tolerated even by many of those suffering from pain in the mobile hip An interesting feature of the final period of the static support test was that most of the probands resumed their preferred mode of support from the first part of the test This was interpreted as a further sign that the support pattern displayed was characteristic of the individual

equal support pattern Thus incidence and degree of pain in the mobile hip was least in the 52 cases who showed preference for the mobile leg

As regards frontal position main support by the fused leg appeared to be facilitated by the neutral or adducted position of the fused leg

In more than half of the 41 cases with main support by the fused leg a combination of the above factors occurred On one hand there was relative shortening and neutral or adducted position of the fused hip and on the other hand pain and/or stiffness of the mobile hip

Symptoms from the knees did not seem to have a decisive influence on the support pattern although an occasionally contributary role was probable Seventy six probands had knee symptoms mostly in the form of slight and/or occasional pain In 52 of these radiographic signs of gonarthrosis were found at follow-up Radiographic changes were more common and slightly more advanced on the fused side

Of the 19 probands who used the fused leg for support 15 had some pain in the knees 10 in the ipsilateral knee (fused side) 1 in the contralateral and 4 in both Of the 52 probands who used the mobile leg for support 13 had knee symptoms 4 in the ipsilateral (fused side) knee 3 in the contralateral and 6 in both Of the 54 probands with equal support 48 had symptoms from the knees 24 in the ipsilateral 6 in the contralateral and 18 in both knees

Pain or fatigue in the lumbar region was a common complaint during protracted standing and sitting Such symptoms were reported by 75 probands 32 of whom felt that this impaired their standing and walking capacity Sixty three of the former and 28 of the latter had radiographic signs of lumbar spondylarthrosis

A slight increase in the incidence of lumbar pain with the degree of flexion in the fused hip was noted Thus one half (19) of the 38 probands with small degrees (10 -29) of flexion compared to three fourths (18) of the 26 with large flexion (40 - 50) angles had back pain

4 Conclusions

The support pattern when standing in a free or preferred manner showed that after arthrodesis of the hip the fused extremity was seldom used as the supporting leg it was intended to become Eighty five percent of the probands either displayed equal support or prefer

forcibly lifting up the mobile side the whole (fused) coxofemoral region can be brought to rotate around the axis of the subtalar joints until the line of gravity coincides with the supporting foot (Fig 6 e) Both these postures require continuous muscular effort for keeping balance along with more or less compensatory scoliosis the dimensions of which is dependent largely on the degree of abduction of the fused hip

The results of the static support test were in agreement with the above considerations Two thirds of the probands loaded the mobile leg with more than half of their body weight and 42% of the total number of probands used the mobile leg for support (> 60 % of b w by choice whereas only 15% chose the fused leg for support The question then arises in what respect the probands loading the fused leg differed from the rest Naturally a number of factors may influence the choice of leg for support e g relative leg length position of the fused hip, state of the mobile hip and symptoms from other adjoining joints chiefly the back and knees

Those probands who mostly loaded the mobile leg were of the opinion that support by the mobile leg was more comfortable whereas main support by the fused leg was more tiring both generally and for the back More seldom the fused leg was spared owing to the feeling that it was still the sick one and had to be protected This impression seemed real for a few probands and may have been a factor the importance of which is hard to estimate A few probands reported that they avoided loading the fused leg in public as they felt their buttocks protruded too markedly

The probands who mostly loaded the fused leg gave entirely different reasons Most of them thought the mobile leg had become too long after the operation Those with large relative shortening of the fused leg were more or less compelled to stand with most of body weight on one leg or the other and some of these probands preferred standing on the fused leg than on the mobile leg, with the fused one hardly reaching the ground This was in agreement with the results of the test as a large, relative shortening of the fused leg appeared to induce support by one leg

Many of the probands in whom the mobile hip had become painful in the interval between the operation and the follow-up examination reported that they had always used the mobile leg for support until it had become painful Only then had they begun to shift more of body weight over to the fused side This applied to many of the probands with an

ence for loading the mobile leg The support pattern registered by Hohman (1962) in 75 hip arthrodesed subjects showed similar results (cf p 22)

Not before the mobile hip had become painful or more painful than preoperatively had more of body weight been shifted to the fused side by a conscious effort This was borne out both by the probands accounts and by the significantly higher incidence and degree of changes and pain in the mobile hip in those probands who displayed equal support and support by the fused leg

Loading on the fused leg appeared to be facilitated by the neutral or adducted position of the fused hip and by shortening of the fused leg On the other hand the degree of flexion of the fused hip was not found to affect the support pattern

The support pattern was very uniform in different parts of the test and shifts were markedly scarce compared with what may be considered usual in normal subjects

In view of the results of the test and the opinion of the probands it was concluded that the alleged supporting role of the fused leg has not been based on factual evidence

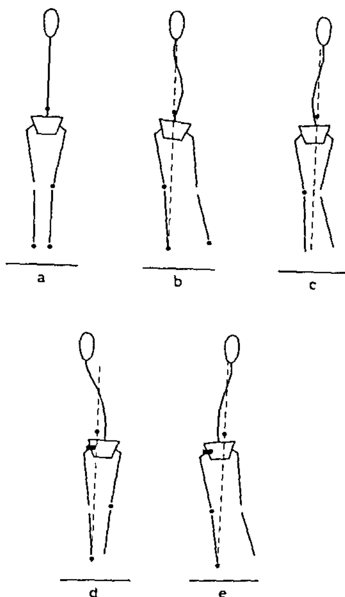


Fig 6 Static Posture in a Healthy Individual
a) Equal Support by both Legs
b) Support by One Leg (Pos Trendelenburg)
c) Support by One Leg (Neg Trendelenburg)
Static Posture after Arthrodesis of One Hip
d) Support by the Fused Leg by leaning the Trunk Toward the Fused Side
e) Support by the Fused Leg by Lifting up The Mobile (Hip) Side and Rotation Around the Axis of the Subtalar Joints

Table X   Observed S gns of Radiograhpic Deterioration of Mobile Hip

68 Cases with Radiog Deter of Mobile Hip	Number	*Increase in Radiographic Index*				Total Increase In Index	Mean Increase In Index
		Osteo phytes	Joint Space	Struct Changes	Double Floor		
Unilateral Coxarth os	31	22	25	11		58	1 9
Bilateral Coxarthros	37	34	44	34	2	114	3 1
T o t a l	68	56	69	45	2	172	2 5

Tabel XI   Rate of Radiographic Deterioration of Mobile Hip in Unilateral and Bilat ral Coxarthrosis Figures within Brackets the 68 Hips which showed Radiographic Deterioration

Follow *Up* Period	Unilateral Coxarthrosis		Bilateral Coxarthrosis		T o t a l	
	Number	Average Increase	Number	Average Increase	Number	Average Increase
<5 years	16 (3)	0 2 (1 0)	8 (2)	0 6 (2 5)	24 (5)	0 3 (1 6)
5 9 "	21 (11)	0 8 (2 0)	23 (18)	1 9 (2 3)	50 (29)	1 3 (2 2)
10 14	14 (7)	1 2 (2 3)	15 (13)	2 6 (3 2)	29 (20)	2 0 (2 9)
15 22	18 (10)	0 9 (1 7)	4 (4)	6 5 (6 5)	22 (14)	1 9 (3 2)
T o t a l	75 (31)	0 8 (1 9)	50 (37)	2 4 (3 1)	125 (68)	1 4 (2 5)

B Radiographic Examination

1 Arthrotic Deterioration of Mobile Hip

a With Regard to Radiographic Appearance at Operation

i Unilateral Coxarthrosis Of the 75 cases without signs of arthrosis of the mobile hip at operation 31 had developed such signs by the time of follow-up (Table IV) The average radiographic severity of the 31 hips was 1 9 index points (range 1 6) (Table X) Of these 31 cases 16 showed only signs of incipient arthrosis In 8 of the latter fused because of secondary arthrosis progress consisted of an osteophyte on one pole The remaining 8 fused because of primary arthrosis showed either narrowing of the joint space or structural changes In the remaining 15 cases reduction of the joint space was the most common finding in both types of arthrosis (9 secondary and 6 primary)

In unilateral coxarthrosis the course of the mobile hip was usually favourable for the first few years Radiographic changes were mostly mild and although the incidence of arthrosis rose sharply after 5 years two thirds of the hips showed no signs of arthrosis up to 10 years after operation Of the remaining third reviewed after a longer interval half the number deteriorated (Table XI)

ii Bilateral Coxarthrosis Of the 50 cases with a varying degree of arthrosis of the mobile hip at the time of operation the average radiographic severity had increased by 3 1 index points (range 1-8) in 37 (Table XI)

radiographic changes Thirty of the present 75 unilateral cases were reviewed 2 to 7 years after operation by which time degenerative changes had appeared in 7 Demigneux et al (1968) found an incidence of 14 of 92 unilateral cases reviewed 5 to 15 years after operation The etiological composition was not stated In the present material 18 of the 42 unilateral cases reviewed 5 to 15 years after operation had developed signs of arthrosis In a series of 75 cases Hauge (1963) found incipient arthrosis in only 6 of the mobile hips examined 5 to 20 years after the operation All but 4 had been fused for tuberculosis or some unspecific inflammation Mean age at follow-up was 36 years The lower incidence in the last two series compared with the present was probably due primarily to the higher percentage of secondary coxarthrosis and the lower average age in these two series

Demigneux et al (1968) reviewed 41 cases fused 5 to 15 years previously because of bilateral coxarthrosis At follow-up 24 had been subjected to mobilizing operations of the other hip (5 before the fusion) Of the remaining cases 14 had showed signs of mild arthrosis of the mobile hip at operation At the review all were found to have deteriorated and 11 of them considerably Merle d Aubigne Ramadier Postel Mozas and Vaillant (1964) reviewed 59 cases arthrodesed 2 1/2 12 years previously for bilateral coxarthrosis Deterioration of the mobile hip had occurred in 31 cases 8 of which had been operated upon Of the present 39 bilateral cases with up to 12 years in follow up time 19 had deteriorated

b   Type of Arthrosis of Fused Hip

Of the 75 unilateral cases 50 hips had been operated for secondary and 25 for primary coxarthrosis Of the 31 probands who developed signs of arthrosis 17 had had secondary and 14 primary arthrosis in the fused hip

The average radiographic deterioration of the mobile hip was 0 7 in the 50 secondary and 1 0 index points in the 25 primary cases Of the 50 secondary cases deterioration of the mobile hip was greatest in the 21 cases operated for arthrotic changes secondary to some developmental disturbance mild in the 18 cases fused because of late effects of coxitis and absent in the 11 cases fused because of late complications of fracture of the femoral neck (Table XIII A 1)

Of the 50 bilateral cases 36 had primary and 14 secondary arthrosis of the fused hip at operation In 28 of the former and in 9 of

Forty one of the bilateral cases had had up to 5 in initial radiographic index Thirty two of these showed progress Average incidence and amount of radiographic progress was roughly the same in these five index groups i e four fifths of the probands and over 3 0 index points increase in each Of the remaining 9 probands with an initial index of 6 or more 5 had progressed on the average 1 8 points

As in unilateral coxarthrosis, joint space reduction was the commonest sign of progress Structural changes occurred two and a half times as often as in unilateral coxarthrosis Eleven of these 37 hips showed only one sign of progress In 4 of these a new osteophyte had formed while in the 7 others the joint space had become narrowed In the remaining 26 cases joint space reduction was also the most common sign (Table X)

The radiographic deterioration of the mobile hip appeared sooner and progressed more rapidly in bilateral than in unilateral coxarthrosis (Table XI) Only one third of these cases had remained stationary for up to 10 years after operation and only one fifth for a still longer interval The radiographic deterioration was also more severe in the bilateral cases (Figs 10-12 p 74-79)

The difference in <u>incidence</u> of radiographic signs of arthrotic deterioration between the unilateral and bilateral cases was significant

Average <u>degree</u> of arthrotic deterioration in the 75 unilateral cases was 0 8 and in the 50 bilateral cases 2 3 index points The difference was significant (Table XII)

Table XII Radiographic Deterioration in Unilateral and Bilateral Coxarthrosis

	Increase in Radiographic Sverity			
	0	1	2	≥3
Unilateral Coxarthrosis	44	16	9	6
Bilateral Coxarthrosis	13	11	8	18
Total	57	27	17	24 = 125

Comments

Hohman (1962) reviewed 75 cases operated upon 1 to 7 years previously because of primary or secondary coxarthrosis Of the hips free from changes at operation he found that one fourth had developed

radiographic changes Thirty of the present 75 unilateral cases were reviewed 2 to 7 years after operation by which time degenerative changes had appeared in 7 Demigneux et al (1968) found an incidence of 14 of 92 unilateral cases reviewed 5 to 15 years after operation The etiological composition was not stated In the present material 18 of the 42 unilateral cases reviewed 5 to 15 years after operation had developed signs of arthrosis In a series of 75 cases Hauge (1963) found incipient arthrosis in only 6 of the mobile hips examined 5 to 20 years after the operation All but 4 had been fused for tuberculosis or some unspecific inflammation Mean age at follow-up was 36 years The lower incidence in the last two series compared with the present was probably due primarily to the higher percentage of secondary coxarthrosis and the lower average age in these two series

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b Type of Arthrosis of Fused Hip

Of the 75 unilateral cases 50 hips had been operated for secondary and 25 for primary coxarthrosis Of the 31 probands who developed signs of arthrosis 17 had had secondary and 14 primary arthrosis in the fused hip

The average radiographic deterioration of the mobile hip was 0 7 in the 50 secondary and 1 0 index points in the 25 primary cases Of the 50 secondary cases deterioration of the mobile hip was greatest in the 21 cases operated for arthrotic changes secondary to some developmental disturbance mild in the 18 cases fused because of late effects of coxitis and absent in the 11 cases fused because of late complications of fracture of the femoral neck (Table XIII A B)

Of the 50 bilateral cases 36 had primary and 14 secondary arthrosis of the fused hip at operation In 28 of the former and in 9 of

Table XIII A Arthrotic Deterioration in 50 Cases of Unilateral Secondary Coxarthrosis

Etiology	Number	Average Deterioration	Average Follow-up Period	Age at Follow-up	Number With Deter
Developmental Disturbances					
Dysplasia	9	1 7	12 years	64 years	6
Cong Dislocation	6	1 0	7	55	2
Epiphysiol Mb Perthes					
Coxa Valga	6	0 9	15	56	3
	21	1 2	13	60	11
Inflammation					
Septic Coxitis	9	0 3	9	50	3
Tuberculous Coxitis	7	0 6	11	51	2
Osteomyelitis R A	2	0 5	3	31	1
	18	0 4	9	49	6
Trauma					
Fract Fem Neck	11	0	10	64	0
Total	50	0 7	10 years	56 years	17

Table XIII B Arthrotic Deterioration in 14 Cases of Bilateral Secondary Coxarthrosis

Etiology	Number	Average Deterior ation	Average Follow Period	Age at Follow-up	Number With Deter
BOTH HIPS					
Developmental Disturb					
Dysplasia	4	1 8	10 years	55 years	4
Cong Dislocation	1	4 0	6	58	1
Coxa Vara	1	0	8	60	0
	6	1 8	9	56	5
Inflammation					
Rheumatoid Arthritis	4	1 5	6	58	2
ONE HIP					
Developmental Disturb					
Epiphysiolysis	1	1 0	7	64	1
Mb Perthes	1	1 0	10	71	1
	2	1 0	9	67	2
Trauma					
Fract of Fem Neck	1	0	10	84	0
Fract of Acetabulum	1	0	14	55	0
	2	0	12	69	0
Total	14	1 4	9 years	60 years	9

the latter the radiographic severity had increased in the mobile hip The average degree was 2 6 index points in the 36 primary and 1 4 points in the 14 secondary cases (Table XIV)

Table XIV Arthrotic Deterioration in 61 Cases of Primary Coxarthrosis

Primary Coxarthrosis	Number	Average Deterior ation	Average Follow up Period	Age at Follow-up	Number With Deter
Unilateral Cases	25	1 0	10 years	63 years	14
Bilateral Cases	36	2 6	10	67 "	28
Total	61	1 9	10 years	66 years	42

Comments

Danielsson (1964) reviewed 91 unoperated cases *(121* hips) from 8 to 12 years (average 11 years) after clinical and radiographic diagnosis of coxarthrosis The aim was to assess the prognosis of coxarthrosis and to provide a standard of comparison for *operated* cases Radiographic changes were evaluated by comparison *of* initial and follow up radiograms according to the scheme used in the present investigation (Table IV) All 121 hips had structural and/or joint space changes at the time of diagnosis The two materials were well comparable as regards number of hips age (cf p 48) and the average duration of the interval Still in the present material 10 of the bi-lateral cases had been reviewed after more than 12 years On the other hand 85% of Danielsson s series had primary coxarthrosis against 50% of the present material

Danielsson found that radiographic changes usually progressed (average 1 4 index points) and that primary coxarthrosis progressed radiographically more than secondary ($1\ 7 \pm 0\ 13$ versus $0\ 7 \pm 0\ 13$)

These figures when compared with radiographic progress in all the primary (61) and secondary (64) cases in the present material were found to be almost identical (1 9 versus 0 8 index points)

As all the hips in Danielsson s series had structural and/or joint space changes at the outset comparison with the bilateral cases was of even greater interest Of the 50 bilateral cases of the present material the primary also progressed radiographically more than the secondary cases

Table XIII A Arthrotic Deterioration in 50 Cases of Unilateral Secondary Coxarthrosis

Etiology	Number	Average Deterioration	Average Follow-up Period	Age at Follow-up	Number With Deter
Developmental Disturbances					
Dysplasia	9	1 7	12 years	64 years	6
Cong Dislocation	6	1 0	7	55	2
Epiphysiol Mb Perthes					
Coxa Valga	6	0 9	15	56	3
	21	1 2	13	60 "	11
Inflammation					
Septic Coxitis	9	0 3	9	50	3
Tuberculous Coxitis	7	0 6	11	51	2
Osteomyelitis R A	2	0 5	3	31	1
	18	0 4	9	49	6
Trauma					
Fract Fem Neck	11	0	10	64	0
Total	50	0 7	10 years	56 years	17

Table XIII B Arthrotic Deterioration in 14 Cases of Bilateral Secondary Coxarthrosis

Etiology	Number	Average Deterioration	Average Follow Period	Age at Follow-up	Number With Deter
BOTH HIPS					
Developmental Disturb					
Dysplasia	4	1 8	10 years	55 years	4
Cong Dislocation	1	4 0	6	58 "	1
Coxa Vara	1	0	8	60 "	0
	6	1 8	9	56 "	5
Inflammation					
Rheumatoid Arthritis	4	1 5	6	58	2
ONE HIP					
Developmental Disturb					
Epiphysiolysis	1	1 0	7	64	1
Mb Perthes	1	1 0	10	71	1
	2	1 0	9 "	67 "	2
Trauma					
Fract of Fem Neck	1	0	10	84 "	0
Fract of Acetabulum	1	0	14 "	55	0
	2	0	12 "	69 "	0
Total	14	1 4	9 years	60 years	9

the latter the radiographic severity had increased in the mobile hip The average degree was 2 6 index points in the 36 primary and 1 4 points in the 14 secondary cases (*Table XIV*)

Table XIV Arthrotic Deterioration in 61 Cases of Primary Coxarthrosis

Pr mary Coxarthrosis	Number	Average D te ior at on	Average Follow up Period	Age at Follow-up	Number With Deter
Unilat ral Cases	25	1 0	10 years	63 years	14
Bilateral Case	36	2 6	10 "	67 "	28
T o t a l	61	1 9	10 years	66 years	42

Comments

Danielsson (1964) reviewed 91 unoperated cases (121 hips) from 8 to 12 years (average 11 years) after clinical and radiographic diagnosis of coxarthrosis The aim was to assess the prognosis of coxarthrosis and to provide a standard of comparison for operated cases Radiographic changes were evaluated by comparison of initial and follow-up radiograms according to the scheme used in the present investigation (Table IV) All 121 hips had structural and/or joint space changes at the time of diagnosis The two materials were well comparable as regards number of hips age (cf p 48) and the average duration of the interval Still in the present material 10 of the bilateral cases had been reviewed after more than 12 years On the other hand 85% of Danielsson s series had primary coxarthrosis against 50% of the present material

Danielsson found that radiographic changes usually progressed (average 1 4 index points) and that *primary coxarthrosis* progressed radiographically more than secondary (1 7± 0 13 versus 0 7± 0 13)

These figures when compared with radiographic progress in all the primary (61) and secondary (64) cases in the present material were found to be almost identical (1 9 versus 0 8 index points)

As all the hips in Danielsson s series had structural and/or joint space changes at the outset comparison with the bilateral cases was of even greater interest Of the 50 bilateral cases of the present material the primary also progressed radiographically more than the secondary cases

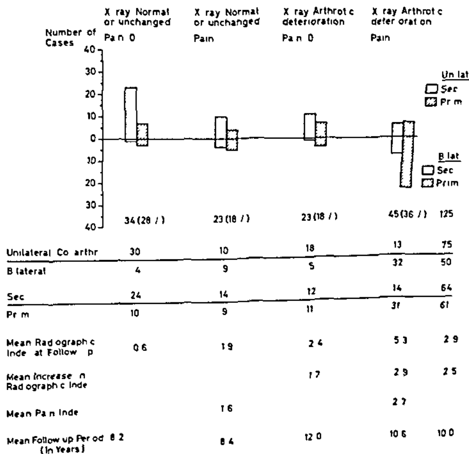
Of Danielssons s material one third showed no progression and in 8 hips signs of regression were observed Of the 50 bilateral cases of the present material one fourth showed no signs of progression but in no instance were signs of regression observed

The difference in radiographic deterioration of the mobile hip in the present 36 bilateral primary cases (2 6 $\pm$ 0 12) and Danielsson s 104 hips (1 7 $\pm$ 0 13) followed up on the average 11 years after a diagnosis of primary coxarthrosis had been made was significant

c Interval Between Operation and Review

The interval was on the average the same for primary and secondary cases (10 years)

In unilateral coxarthrosis the average interval was over 3 years longer for the cases in which degenerative signs had appeared (Fig 7) Of the 43 cases where the interval was less than 10 years 14 displayed signs of deterioration compared with 17 of the 32 reviewed after a longer interval (Table XI)



	X ray Normal or unchanged Pa n 0	X ray Normal or unchanged Pain	X ray Arthrot c deterioration Pa n 0	X ray Arthrot c deter orat on Pain	
	34 (28 /)	23 (18 /)	23 (18 /)	45 (36 /)	125
Unilateral Co arthr	30	10	18	13	75
B lateral	4	9	5	32	50
Sec	24	14	12	14	64
Pr m	10	9	11	31	61
Mean Rad ograph c Inde at Follow p	0 6	1 9	2 4	5 3	2 9
Mean Increase n Rad ograph c Inde			1 7	2 9	2 5
Mean Pa n Inde		1 6		2 7	
Mean Follow up Per od (In Years)	8 2	8 4	12 0	10 6	10 0

Fig 7 Incidence and Degree of Radiographic Deterioration and Pain

Of the 75 unilateral cases 19 were reviewed after 15 to 22 years Eleven of these showed an increase in radiographic severity from 1 to 6 points (average 2 1 index points) whereas 8 had remained stationary

In bilateral coxarthrosis the cases with radiographic signs of progression had 3 years longer average interval than in the remaining 13 stationary cases (Fig 7) Of 31 cases reviewed after periods up to 10 years 20 had deteriorated compared with 17 of the 19 reviewed after a long interval

Only 4 of the bilateral cases had been reviewed after 15 to 22 years All 4 showed heavy radiographic progress average 5 2 points (range 5-8) Of the 13 cases who had not progressed the interval was less than 5 years in 6 between 5 and 10 years in 4 and 10 to 15 years in 3 The average for all 13 cases was 6 4 years

Comments

In the unilateral cases the incidence of radiographic changes appeared to have increased more than their severity while in the bilateral cases radiographic severity had increased steadily with time (Table XII)

Hohman in his series (cf p 38) found an incidence of 10 % at review from 1 to 2 years and 45% after 6 years or more The incidence in the present material was 10 of 35 cases reviewed after 2 to 6 years and 58 of 90 cases reviewed after a longer period

d Frontal Position of Fused Hip

Eighty seven (70%) of the probands had various degrees of abduction (>5) from the neutral angle The average *degree and* incidence of radiographic deterioration was slightly higher in the abducted position than in adduction or the *neutral* position (Table XV) but the difference was not statistically *significant* The ratio of unilateral and bilateral cases in the three position groups was adduction 1 4/1 *neutral* 1 5/1 and abduction 1 5/1 Thus the same proportion in all three groups

Of Danielssons s material one third showed no progression and in 8 hips signs of regression were observed Of the 50 bilateral cases of the present material one fourth showed no signs of progression but in no instance were signs of regression observed

The difference in radiographic deterioration of the mobile hip in the present 36 bilateral, primary cases (2 6 $\pm$ 0 12) and Danielsson s 104 hips (1 7 $\pm$ 0 13), followed up on the average 11 years after a diagnosis of primary coxarthrosis had been made, was significant

c Interval Between Operation and Review

The interval was on the average the same for primary and secondary cases (10 years)

In unilateral coxarthrosis the average interval was over 3 years longer for the cases in which degenerative signs had appeared (Fig 7) Of the 43 cases where the interval was less than 10 years 14 displayed signs of deterioration compared with 17 of the 32 reviewed after a longer interval (Table XI)

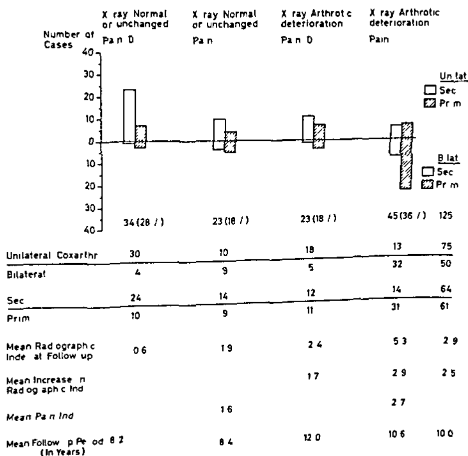


Fig 7 Incidence and Degree of Radiographic Deterioration and Pain

were observed in only 5 of the 24 probands reviewed up to 5 years after the operation The fact that half of the unilateral and four fifths of the bilateral cases were found to have deteriorated by the time of review more than 5 years after operation and that the radiographic deterioration was more severe than in a comparable unoperated series (Danielsson 1964) and the absence of radiographic signs of regression did not suggest unburdening of the mobile hip

Training the arthrodesed subject to load the fused leg has been suggested by authors who at review had found that many of their cases had developed arthrosis and/or pain in the mobile hip (Leger 1956 Hohman 1962 Mach 1964 Demigneux 1967) It can hardly be expected however that such a measure would permanently affect their standing habits Standing is largely an unconscious effort as long as it does not incur discomfort or pain With easy energy saving standing restricted to one side the arthrodesed subject will as a rule automatically exploit the pain-free mobile leg for this purpose Furthermore, biological factors and the forces acting on the joint during gait, are bound to be more important for the fate of the mobile hip than static strain

The compensatory demands on the mobile hip during walking are well documented (Steindler 1955 Seevald and Debrunner 1964 Casuccio 1964 Ducroquet 1965) The only way the fused leg can be swung forward is by way of the pelvis with the mobile hip as a pivot This occurs during the stance phase of the mobile leg when the joint is being loaded with at least twice the body weight as the pelvis tilts and rotates around the femoral head It is reasonable to expect that such compensatory exertion hastens the degeneration of any joint not biologically fit and congruent It may be argued that the stiffness of the fused hip before the operation had placed similar demands on the mobile hip But as a successful arthrodesis leads to a more active life the compensatory strain on the mobile hip will still be increased

Other mechanical factors of probable importance for the fate of the mobile hip were a) loss of suppleness of the gait as the remaining normal segments of the extremity can only partially compensate for the loss of the hip joint pelvic tilt and rotation being important factors in decreasing the vertical displacement of the center of gravity of the body (Saunders Inman and Eberhart 1953) b) reduction of the contact area in the mobile hip due to the commonly occurring inclination of the pelvis toward the fused side (Pagani Morosini and Buratti 1967) and c) walk way studies have shown that the stance

Table XV Radiographic Deterioration versus Frontal Position of Fused Hip Figures within Brackets the 68 Cases which showed Radiographic Deterioration

	Adduction	Neutral	Abduction
Unilateral Coxarthrosis	7 (4)	35 (11)	33 (16)
Average Degree	0 7	0 6	0 9
Bilateral Coxarthrosis	5 (3)	23 (16)	22 (18)
Average Degree	2 0	1 9	2 8
T o t a l	12 (7)	58 (27)	55 (34)
Average Degree	1 3 (2 2)	1 1 (2 4)	1 7 (2 8)

Comments

The abducted position of the fused hip was for a long time recommended to compensate for shortening of the leg The rationale was that when such shortening was marked this source of compensation could be utilized for obviating unsightly aids for providing better feeling of contact with the ground ("Bodengefühl Machacek 1956) and facilitate walking and standing without shoes

The adverse effects of marked abductions have since been well recognized however and corrective osteotomies have not infrequently been reported (Hauge 1963) In the present material 3 such late osteotomies had been *preformed* The abducted position of the hip renders the gait awkward and requires circumduction of the fused leg in the swing phase and an increased strain is thrown on the back and the mobile hip during walking and standing with time entailing a risk of degenerative changes with symptoms (Fürmaier 1959 Hohman 1962 Seevald and Debrunner 1964 and Demigneux Rainaut and Cedart 1968)

The fact that radiographic deterioration even though only slight was largest in the abducted position suggests that this may have been a contributory factor

2 Discussion

Radiographic signs of arthrotic deterioration of the mobile hip

were observed in only 5 of the 24 probands reviewed up to 5 years after the operation The fact that half of the unilateral and four fifths of the bilateral cases were found to have deteriorated by the time of review more than 5 years after operation and that the radiographic deterioration was more severe than in a comparable unoperated series (Danielsson 1964) and the absence of radiographic signs of regression did not suggest unburdening of the mobile hip

Training the arthrodesed subject to load the fused leg has been suggested by authors who at review had found that many of their cases had developed arthrosis and/or pain in the mobile hip (Leger 1956 Hohman 1962 Mach 1964 Demigneux 1967) It can hardly be expected however that such a measure would permanently affect their standing habits Standing is largely an unconscious effort as long as it does not incur discomfort or pain With easy energy saving standing restricted to one side the arthrodesed subject will as a rule automatically exploit the pain free mobile leg for this purpose Furthermore biological factors and the forces acting on the joint during gait are bound to be more important for the fate of the mobile hip than static strain

The compensatory demands on the mobile hip during walking are well documented (Steindler 1955 Seevald and Debrunner 1964 Casuccio 1964 Ducroquet 1965) The only way the fused leg can be swung forward is by way of the pelvis with the mobile hip as a pivot This occurs during the stance phase of the mobile leg when the joint is being loaded with at least twice the body weight as the pelvis tilts and rotates around the femoral head It is reasonable to expect that such compensatory exertion hastens the degeneration of any joint not biologically fit and congruent It may be argued that the stiffness of the fused hip before the operation had placed similar demands on the mobile hip But as a successful arthrodesis leads to a more active life the compensatory strain on the mobile hip will still be increased

Other mechanical factors of probable importance for the fate of the mobile hip were a) loss of suppleness of the gait as the remaining normal segments of the extremity can only partially compensate for the loss of the hip joint pelvic tilt and rotation being important factors in decreasing the vertical displacement of the center of gravity of the body (Saunders Inman and Eberhart 1953) b) reduction of the contact area in the mobile hip due to the commonly occurring inclination of the pelvis toward the fused side (Pagani Morosini and Buratti 1967) and c) walk way studies have shown that the stance

phase on the fused side is diminished and prolonged on the mobile side (Seevald and Debrunner 1964) or on the "good side" in limping (Rydell 1966)

Other factors of possible importance were age at operation (within the etiological groups), sex body weight and occupation No appreciable influence of these factors could be discerned

3 Conclusions

Incidence of radiographic deterioration of the mobile hip in the present material was similar to that found in comparable published series The severity of radiographic deterioration in the bilateral cases was however significantly higher than in Danielsson s series of unoperated cases with the same average follow-up interval

Arthrodesis of the hip was generally well tolerated by the contralateral hip provided the latter was free from changes at the outset and the susceptibility associated with the primary form of coxarthrosis

The professed relief of the mobile hip when slightly or moderately affected was not sustained by the findings of the present investigation as with time the majority of these cases showed heavy increase in radiographic severity The high rate of deterioration in bilateral coxarthrosis particularly the primary form strongly indicated that the fate of the mobile hip was dependent primarily on biological factors i e its ability to withstand the mechanical surcharge thrown upon it On the other hand the fate of the hip was not found to vary appreciably with such factors as sex occupation or body weight

It was concluded that the increase in radiographic severity in the present material compared with that of Danielsson s series refutes the hypothesis that arthrodesis results in mechanical relief of the mobile hip

C Clinical Examination

1 Pain in Mobile Hip

a Incidence

Sixty eight probands had pain in the mobile hip at follow-up (not to be confused with the 68 probands with arthrotic deterioration) Twenty one had had pain also before the operation Of the latter 10 had become worse 8 were unchanged and 3 had less pain than before Thus half of the probands had either developed pain or become worse The incidence of pain was significantly higher in the bilateral cases (Fig 7)

b Severity

At follow-up 35 probands had mild 21 moderate and 12 severe pain in the mobile hip (cf p 19) In two thirds of the painful hips radiographic severity had increased Degree of pain was significant ly higher in these than in the remaining third with no increase (Fig 7) The average increase in radiographic severity was three times as large in the 33 hips with moderate or severe pain as in the 35 hips with mild pain

Of 43 overweight probands 21 had pain in the mobile hip Average severity of pain in these was the same (2 4 index points) as in the remaining 47 hips

c Pelation to Range of Motion

Thirty-one of the mobile hips had less than 90 degrees of flexion and all but one of these had a flexion contracture Twenty-eight of these had shown radiographic changes at operation and 23 had since progressed

In all 35 probands had a flexion contracture in the mobile hip average 21 degrees (range 10 65) Thirty of these hips had shown changes at operation Twenty nine of the 35 probands had pain in the mobile hip with an average score of 2 8 index points

Comments

Degel (1957) reviewed 115 arthrodesed cases from 3 to 8 years after operation In thirty nine (34%) the mobile hip had become pain-

ful or worse, it was unchanged in 61 and had become painless or better in 10

Of 75 cases subjected to arthrodesis Hohman (1962) found that the mobile hip had become painful or worse within 1-7 years in 37%

In the present material the incidence found at review within 10 years of the operation was the same as in the above two series namely 27 of 74 cases (average 2 6 index points) The corresponding figures for those examined after a longer period were 30 of 51 (average 2 2 points)

In his unoperated series, Danielsson (cf p 41) found no relation between pain and etiology of the disease or sex Two thirds of the hips in his series had become less painful during the follow-up period In contrast, in half of the present material the mobile hip had become painful or worse (Table XVI)

Table XVI Incidence of Pain in the Present Material compared with Danielsson s Series (1964)

Degree of Pain	Danielsson (1964)			The Present Material		
	Male	Female	Total	Male	Female	Total
Developed Pain (or More Severe)	10	10	20	19	38	57
Unchanged	3	11	14	2	6	8
Less Severe	28	42	70	2	1	3
Always Painless	11	4	15	25	32	57
Total	52	67	119	48	77	125

At the time of diagnosis all the hips included in Danielsson s series had structural and/or joint space changes For comparison 27 of the present 43 hips with such changes at operation had become painful or worse The average age in Danielsson s series was 10 years higher in primary and 6 years higher in secondary coxarthrosis This may have played some role as the amount of activity and work are likely to be less in the higher age groups

Danielsson also studied the correlation between the severity of pain and contractures in various planes in 123 hips He found that this correlation was strongest for flexion contracture In the present material two thirds of the moderately or severely painful hips were found among the 35 with flexion contractures

At the time of operation 12 probands already had a pension 8 because of age and 4 because of disability In the remaining 113 cases one of the chief goals of the operation was to restore working capacity Of the 113 cases 21 were granted an old age (5) or disability (16) pension within 3 years after operation and never resumed working Of the 92 cases who resumed work 56 were females and 36 males

Return to the same type of work as before operation was more common among those who had light occupations than among those with ' moderate or ' heavy' work (Table XVII) Two thirds of those who returned to their former occupation had been operated upon for unilateral coxarthrosis (Table XVIII)

Table XVIII Working Capacity After Operation

Working Capacity After Operation	Unilateral Cases		Bilateral Cases		Total
	Primary	Secondary	Primary	Secondary	
Resumed working after op					
Same work as before op	7	32	12	8	59
Lighter work than before	11	11	8	3	33
	18	43	20	11	92(74%)
Unable to resume work					
Disability Pension	4	3	8	1	16
Age Pension		1	4		5
	4	4	12	1	21(17%)
Pensioned before op					
Disability Pension	1	1	1	1	4
Age Pension	2	2	3	1	8
	3	3	4	2	12(9%)
Total	25	50	36	14	125(100%)

Of the 113 cases 69 had unilateral and 44 bilateral coxarthrosis at the time of operation Of the former 61 returned to some form of work against 31 of the latter

The interval between operation and resumption of work ranged from 3 months to 2 1/2 years average 11 5 months The average interval did not vary with category of work It was 11 8 months in the 61 unilateral cases and 10 8 months in the 31 bilateral cases It was on the average 10 4 months for males and 12 2 months for females (fig 8)

Table XVII Type of Work before and after Operation
Probands not granted Pension at the Time of Operation

Type of Work Before Operation	Number	Work after Operation				
		Heavy	Moderate	Light	Slight	None
Heavy	26	10	4	6	1	5
Moderate[1)]	43		16	10	9	8
Light[2)]	25		1	18	3	3
Slight[3)]	19				14	5
Total	113	10	21	34	27	21

1) E g factory work all work in large household (≥4 persons), all work in small household (<4 persons) + extra work

2) E g all work in small household light manual labour

3) E g all work in small household except cleaning clerical work

Types of Work Represented

Males (42)

Heavy Farmer or farm labourer (10) construction worker (5) unskilled labourer (4) factory worker (3) mason (2) forester (1) well digger (1)

Moderate Industry worker (2) butcher (1) baker (1) cooper (1) house cleaner (1) electrician (1) wholesaler (1) news-stand salesman (1) automobile reparator (1)

Light Electrical technician (1) engineer-salesman (1) bicycle mechanic (1)

Slight Director (1) light industry worker (1) clerk (1)

Females (71)

Heavy None

Moderate Housewife (5) housewife + (house-cleaning farming saleswoman gardener librarian secretary)(24) waitress (2) house-cleaner (1) home-worker (1)

Light Housewife (18) housewife + (bookkeeping shop assistant)(2) sales manager (1) part-day nurse (1)

Slight Housewife (8) clerk (2) managing director (1) part-time shop assistant (1) secretary (1) maid (1) teacher (1) fur seamstress (1)

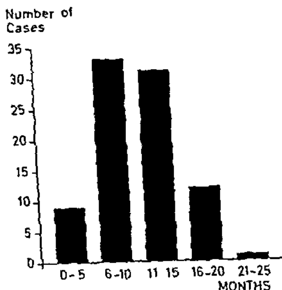


Fig 8 Interval Between Arthrodesis and Resumption of Work in 92 Cases

Sixty four probands were pensioners by the time of the review Thirty-one were receiving an old age pension and 33 a disability pension

Of the 31 probands who were receiving an old age pension, 8 had been pensioners already before the operation 5 within 3 years of the operation and had not resumed work and the remaining 18 had reached retirement age after having worked from 2 to 18 years (average 6 6 years) after the operation Of the 31 probands 22 had been operated upon because of primary coxarthrosis (Table XIX)

Of the 33 probands who were granted a disability pension, 4 had been pensioned off before the operation 16 within 3 years of operation and had not resumed work and a further 13 after having worked for 1 to 20 years (average 6 4 years) after operation Of the 33 probands 23 had been operated for primary coxarthrosis (Table XIX)

Of the 61 probands still working at the time of the review 46 were still engaged in the same occupation as before operation (Heavy 5 Moderate 13 Light 15 and Slight 13) whereas 15 had taken up lighter work Six of the 61 probands were receiving a partial disability pension Over half of these 61 probands had been operated upon be-

Table XIX Work and Pension after Arthrodesis for Unilateral and Bilateral Coxarthrosis

Type of Coxarthrosis	Pension Before op		Pension After op No Work		Age Pension after Op after having worked for (years)					Disability Pension after Operation Having worked for (years)					Still working at Follow-up (years)					Total
	Age Pens	Disab Pens	Age Pens	Disab Pens	1-5	6-10	11-15	16-20	20-25	1-5	6-10	11-15	16-20	21-25	1-5	6-10	11-15	16-20	21-25	
<u>Unilateral</u>																				
Secondary Coxarthrosis	2	1	1	3	1	2		1		1			1		12	14	5	5	1	50
Primary Coxarthrosis	2	1		4	3		2			4	1				4	4				25
<u>Bilateral</u>																				
Secondary Coxarthrosis	1	1		1		1				1		1			2	5	1			14
Primary Coxarthrosis	3	1	4	8	5	1	1	1		2	2				3	5				36
Total	8	4	5	16	9	4	3	2		8	3	1	1		21	28	6	5	1	
	12		21		18					13					61					125

cause of unilateral secondary coxarthrosis (Table XIX)

In primary coxarthrosis the most common reason for a disability pension was pain and/or stiffness of the mobile hip Seventeen of the 23 primary cases had been granted a disability pension for this reason Five of the 10 secondary cases had been granted a disability pension because of pain and/or stiffness of the mobile hip Common associated causes in both categories were obesity cardiac trouble, a protracted postoperative course sometimes with reoperations symptoms referable to other joints (back and knees) and mental depression In some cases difficulties in finding suitable work was probably a contributary factor

Comments

Working capacity is at least temporarily frequently improved or restored after arthrodesis of the hip The frequency with which this occurs depends on a number of factors such as age general health type of work etc (Karlen 1944 Mayr 1954 and Acchiapati 1962)

In the present material the chief difference in this respect was found between probands operated for secondary and primary coxarthrosis Working capacity was improved more often and was more lasting among the former Disability pension had since the operation been granted to 8 (12%) of the former and 21 (34%) of the latter

3 Restriction of Function

By assessing and grading some important daily activities the degree of restriction of function in different parts of the series was compared (Table XX)

Walking Distance The probands assessment of their walking capacity was found to reflect their general functional capacity Thus the 62 who stated that they could walk over 1 5 kilometres had a far better over-all functional capacity than the remaining 63 (Fig 9 Table XXI)

Twenty probands (16%) thought that they had recovered their walking capacity after the operation 14 had been fused for unilateral and 6 for bilateral coxarthrosis Only in 3 of the 20 cases were radiographic signs of progress in the mobile hip demonstrable

Thirty six probands (29%) claimed pain in the mobile hip to be the main cause of reduced walking ability The index of radiographic

Table XX Activities of Daily Living

		Unilateral Coxarthrosis		Bilateral Coxarthrosis		Total
		Secondary	Primary	Secondary	Primary	
Walking Capacity						
Unaided	0	35	11	7	5	58
With one stick	1	11	10	6	22	49
With two sticks	3	3	1	1	8	13
With two trestles	4	1	3	—	1	5
Total		24(0 5)	25(1 0)	9(0 6)	30(1 4)	125
Walking Distance						
≥1 500 Metres	0	33	15	5	9	62
400 1 500 Metres	1	11	3	5	16	35
100 400 Metres	2	6	7	4	8	25
Less than 100 M	3				2	2
Not outdoors	4	—	—	—	1	1
Total		23(0 5)	17(0 7)	13(0 9)	42(1 2)	125
Stairs						
Yes	0	39	17	11	20	87
With difficulty	1	11	8	3	15	37
No(only with help)	3	—	—	—	1	1
Total		11(0 2)	8(0 3)	3(0 2)	18(0 5)	125
Toilet						
Yes	0	36	15	9	27	87
With difficulty	1	14	10	5	9	38
No(only with help)	3	—	—	—	—	0
Total		14(0 3)	10(0 4)	5(0 4)	9(0 2)	125
Dressing						
Yes	0	40	2	13	23	98
With difficulty	1	9	2	1	11	23
No(only with help)	3	1	1	—	2	4
Total		12(0 2)	5(0 2)	1(0 1)	17(0 5)	125
Bathing						
Yes	0	23	5	4	10	47
With difficulty	1	17	10	7	14	48
No(only with help)	3	10	10	3	12	35
Total		47(0 9)	40(1 6)	16(1 1)	50(1 4)	125
Working Capacity After Operation						
Heavy Physical	0	5	1	1	3	10
Moderate	1	10		4	6	22
Light	2	13	10	4	7	34
Slight	3	15	5	2	4	26
None	4	7	7	3	16	33
Total		109(2 2)	65(2 6)	30(2 1)	96(2 7)	125
Total		241(4 9)	170(6 8)	77(5 4)	285(7 9)	125(6 2)

75 Unilateral Cases	5 5 Points	64 Secondary Cases	5 0 Points
50 Bilateral Cases	7 2 Points	61 Primary Cases	7 5 Points

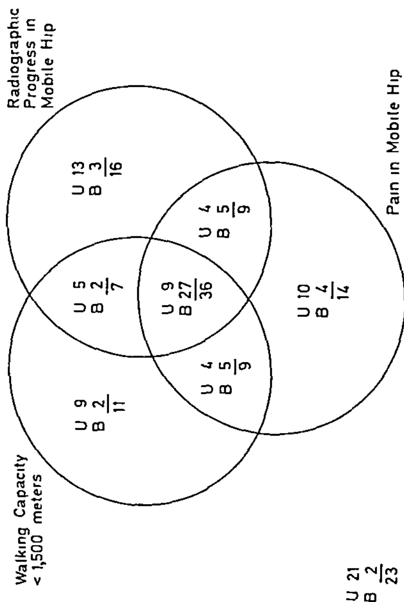


Fig 9 Walking Capacity Versus State of Mobile Hip in Unilateral (U) and Bilateral (B) Coxarthrosis

Table XX Activities of Daily Living

		Unilateral Coxarthrosis		Bilateral Coxarthrosis		Total
		Secondary	Primary	Secondary	Primary	
Walking Capacity						
Unaided	0	35	11	7	[illegible]	58
With one stick	1	11	10	6	22	49
With two sticks	3	3	1	1	8	13
With two trestles	4	1	3	—	1	5
Total		24(0 5)	25(1 0)	9(0 6)	30(1 4)	125
Walking Distance						
≥ 1 500 Metres	0	33	15	5	9	62
400 1 500 Metres	1	11	3	5	16	35
100 400 Metres	2	6	7	4	8	25
Less than 100 M	3				2	2
Not outdoors	4	—	—	—	1	1
Total		23(0 5)	17(0 7)	13(0 9)	42(1 2)	125
Stairs						
Yes	0	39	17	11	20	87
With difficulty	1	11	8	3	15	37
No(only with help)	3	—	—	—	1	1
Total		11(0 2)	8(0 3)	3(0 2)	18(0 5)	125
Toilet						
Yes	0	36	1[illegible]	9	27	87
With difficulty	1	14	10	5	9	38
No(only with help)	3	—	—	—	—	0
Total		14(0 3)	10(0 4)	5(0 4)	9(0 2)	125
Dressing						
Yes	0	40	2[illegible]	13	23	98
With difficulty	1	9	2	1	11	23
No(only with help)	3	1	1	—	2	4
Total		12(0 2)	5(0 2)	1(0 1)	17(0 5)	125
Bathing						
Yes	0	23	5	4	10	42
With difficulty	1	17	10	7	14	48
No(only with help)	*3*	*10*	*10*	3	12	35
Total		47(0 9)	40(1 6)	16(1 1)	50(1 4)	125
Working Capacity After Operation						
Heavy Physical	0	5	1	1	3	10
Moderate	1	10	2	4	6	22
Light	2	13	10	4	7	34
Slight	3	15	5	2	4	26
None	4	7	7	3	16	33
Total		109(2 2)	65(2 6)	30(2 1)	96(2 7)	125
T o t a l		243(4 9)	170(6 8)	77(5 [illegible])	285(7 9)	125(6 2)

75 Unilateral Cases 5 5 Points
50 Bilateral Cases 7 2 Points

64 Secondary Cases 5 0 Points
61 Primary Cases 7 5 Points

severity at the review was on the average 4 8 index points for these 36 hips with an average increase in index of 2 5 points The pain index was 2 8 points

Of the 63 probands who could only walk less than 1 5 kilometres 52 had pain and/or showed radiographic progress in the mobile hip Reduced walking capacity was significantly more common among the bilateral cases (Table XXI)

Walking Outside Most of the 49 probands that used one stick carried it in the hand on the operated side For the 58 probands who could walk unaided arthrotic progress was on the average 0 6 index point for the 49 using one stick 1 9 points for the 13 using two sticks 3 0 points and for the 5 probands using two trestles 1 0 point That the progression among the 5 last probands using trestles was so slight was explained by the fact that only one of them used trestles because of symptoms in the mobile hip whereas the rest used them mainly for balance outdoors The latter 4 probands had markedly reduced mobility of the ipsilateral knee one of which was ankylotic as a result of an intraarticular fracture

Only 35 probands stated that walking on snow or in slippery roads was not difficult whereas 65 had difficulties and 25 never went out alone in such weather Twice as many probands had difficulties in walking uphill (78) as downhill (34) and 13 could manage neither

Stairs Most of the probands had no difficulty in walking up or down stairs Theoretically the smaller the angle of flexion in the fused hip the more difficult it is to climb stairs In the present material no such correlation was found Thirty-eight probands had trouble getting on a bus or a train and 19 could not do so without help

Difficulties in getting into a car were common (43 probands) and many could only get in from one side i e with the mobile leg first Some of the probands always had to sit in the front seat in order to have enough room for the stiff leg

Toilet Seventy per cent of the probands could manage without much difficulty One third of the total number of probands used a heightened toilet seat and 20 had put handles on the wall to facilitate sitting down and rising from the toilet

Twenty-four of the females had difficulties when passing urine Thus 21 were troubled by urine running down the stiff thigh and 9 of these plus 3 others were troubled by the stream of urine tending

Table XXI Comparison between 62 Probands with Walking Capacity of 1 500 metres or more and 63 Probands with less

Walking Distance	Unilat Coxarthr		Bilat Coxarthr		Number	Mean Age at Foll -up	Restriction of Function	Mean R Index at Foll -up	Mean Increase in Rad Index	Mean Pain Index	Sex	
	Sec	Prim	Sec	Prim							Male	Females
≥1 500 m	35	15	5	9	62	58 4 yrs	3 5	1 3	0 6	0 4	24	38
<1 500 m	17	10	9	27	63	63 9	8 9	4 4	2 1	2 1	24	39
Total	50	25	14	36	125	61 2 yrs	6 2	2 9	1 4	1 3	48	77

the operation Many daily activities could be mastered only with difficulty and some had since the operation become unsurmountable obstacles especially for the elderly probands Stiffness of the fused hip in association with pain in other joints particularly the mobile hip were the most common reasons for all degrees of disability

5 Conclusions

Arthrodesis of the hip proved to be an effective method of eliminating the invalidity caused by pain and contractures in the arthrotic joint As a measure of this fact three fourths (92) of the probands had been able to resume work most (59) of whom had returned to their former occupation

However arthrodesis of the arthrotic hip is generally performed in the latter half of life when adaptability to changed conditions has become decreased Consequently probands with the primary form of coxarthrosis particularly when bilateral showed far less good functional results and the lowest rate of restored working capacity whereas the opposite was true of probands with secondary coxarthrosis especially those with unilateral affection

It was concluded that as functional capacity after arthrodesis of the hip was largely dependent on age and painfree compensatory motion of adjoining joints most important of which was the mobile hip the total functional gain was often of a temporary character

to run in front of the toilet bowl For 19 of the women these difficulties were constant and quite distressing Some of them always carried a plastic container in their bags when away from home to prevent embarrassment Seven of the total number of probands had not been able to use a toilet seat heightener and three had ever since the operation used the toilet in a standing positon

Dressing Except for socks and shoes dressing was not difficult for 98 (78%) of the probands

Putting on sock and shoe on the operated side proved to be an obstacle for nearly all of the probands This was frequently solved by the help of another person or by the use of special aids Only four probands could tie the shoelace on the fused side

In addition to socks and shoes putting on trousers was the commonest difficulty Many had learned to use special aids or their walking sticks upside-down as a hook to make this task easier Daily dressing time was assessed to be normal for 39 probands (2-5 min prolonged for 57 (5-10 min) and markedly prolonged for 29(>10 min)

Bathing Eighty three probands (66%) had more or less difficulties when taking a bath Thirty-five were dependent on help whereas others assumed a kneeling position or had special seats made for the bath Still others had replaced the bath by a shower All were dependent on help for cutting townails on the fused side

4 Discussion

In coxarthrosis loss of function is caused by pain faulty positions and decrease in range of motion By arthrodesis two factors are permanently abolished at the price of eliminating what useful motion there may have been left in the joint But one of the paradoxes of arthrodesis of the hip was the fact that its first goal i e complete abolishment of motion in the joint in order to increase the overall functional capacity of the individual imposed serious restrictions on his pursuits

Most of the probands who before the operation had been on the brink of permanent invalidity were glad to have sacrificed the remaining motion in the joint to obtain freedom from pain For others the 'completeness of the stiffness had come as a shock and some of the probands had a period of mental depression after discharge when faced with the tasks of daily living and a few still bitterly regretted

C Methods

The investigation comprised a registration of the static support pattern a comparative study of preoperative and follow up radiograms of the mobile hip and a clinical examination

The static support test was performed with the aid of two electronic scales one for each foot which were calibrated to the weight of the proband The difference in loading between the two scales during a certain period could then be calculated from the tracings on an ink-writer The purpose of the test was to ascertain the static support pattern in free and in instructed modes of standing (cf p 13) The test lasted for 20 minutes

The radiographic examination comprised radiograms of the hips pelvis lumbar spine and knees The chief aims of the radiographic examination were a) to assess radiographic signs of arthrotic deterioration of the mobile hip by a comparison with the preoperative radiograms according to a numerical index (Table IV) and b) radiographic determination of the degree of ab- or adduction of the fused hip

The clinical examination aimed chiefly at recording a) range of motion and degree of pain in the mobile hip b) degree of flexion of the fused hip c) state of lumbar spine and knees and d) the probands accounts of their ability to perform daily activities and of their working capacity

Chapter III RESULTS

A Static Support Test

The test showed that when standing easy for 10 minutes only 15% of the probands used the fused leg for support (> 60% f l) whereas both legs were loaded fairly evenly (40% 60% f l)by 43% and the mobile leg was used for support by 42% of the probands

There was a distinct difference in the support pattern according to the state of the mobile hip Thus arthrotic changes and pain were significantly more prevalent in the cases with equal support and those who preferred the fused leg for support than in those who preferred the mobile leg Further loading of the fused leg appeared to be facilitated by the neutral and adducted position of the fused hip and by shortening of the fused leg

IV SUMMARY

Chapter I INTRODUCTION

Since the beginning of the century arthrodesis has been one of the leading methods used in the surgical treatment of coxarthrosis According to many authors arthrodesis of one hip in bilateral coxarthrosis provides the patient with a supporting leg so that the mobile hip is correspondingly relieved from mechanical strain

The aims of the investigation were to find a) to what extent the fused hip was used for static support b) the incidence rate and degree of radiographic deterioration of the mobile hip and c) the incidence and degree of pain in the mobile hip and the influence of pain on daily activities and working capacity

Chapter II MATERIAL AND METHODS

A Classification

The cases were classified as unilateral or bilateral coxarthrosis on the basis of preoperative radiograms Distinction between primary and secondary coxarthrosis was based on the history and on radiographic appearance

B Material

The investigation was based on a follow-up examination of 125 probands who had undergone arthrodesis of the hip 2 to 22 years previously (average 10 years) for unilateral or bilateral coxarthrosis in the two forms of the disease the primary and secondary

There were 77 females and 48 males The average age was 52 years at the time of operation and 61 at the review It was the same in both sexes In 61 cases with primary coxarthrosis mainly bilateral the average age at the review was 66 years and in 64 with secondary coxarthrosis mainly unilateral 57 years

in a joint initially affected On the basis of these findings and in comparison with Danielssons s (1964) series of unoperated cases (cf p 42) the prognosis of the mobile hip in bilateral coxarthrosis especially of the primary type was considered poor

C Clinical Examination

The working capacity and gross functional capacity was often improved or restored after healing of the arthrodesis Ninety-two (74%) of the probands were able to resume work 59 (47%) in their former occupations

The extent and permanency of recovery was dependent on the state of other joints especially the other hip and on the proband s age Consequently probands with the primary form of coxarthrosis particularly when bilateral showed far less good functional results and the lowest rate of restored working capacity whereas the opposite was true of those with secondary coxarthrosis especially in unilateral affection

It was concluded that as long as the hip arthrodesed subject was relatively young with no other joints affected the adverse effects of the arthrodesis were more easily neutralized In the older age groups particularly in primary coxarthrosis the combined effects of advancing age and changes in the opposite hip frequently caused an early diminution of the functional gain achieved

The instructed modes of standing showed that 90% of the probands could use either leg for support for a period of 2 minutes whereas nearly one third of the probands could not distribute body weight evenly between the legs for a period of 5 minutes Even loading of both legs was rendered more difficult by large discrepancies in leg length

The support pattern in Romberg s test revealed that most of the probands resumed their support pattern displayed in the first part of the test

As regards the leg generally used for support in daily life the findings were in agreement with the opinion of 75% of the probands Those whose opinion differed from the results showed no preference for either leg

Compared with what may be considered normal the number of shifts was markedly small especially among those who showed a distinct preference for uneven loading

It was concluded that the fused leg was generally not used for chief support in standing and did not afford relief of the mobile hip The great majority of the probands had loaded mainly the mobile leg as long as it could be comfortably used for this purpose

B Radiographic Examination

The radiographic examination revealed signs of arthrotic deterioration of half of the mobile hips and that the prognosis of the mobile hip was not uniform

A marked difference depending chiefly on two factors was observed i e whether or not the mobile hip was initially affected with arthrotic changes and whether the other hip had been fused for primary or secondary arthrosis This strongly suggested that the dominant factor deciding the future of the mobile joint was of biological nature Thus the mobile hip fared best in the absence of the above factors and by far worst in the presence of both

The frequency and severity of radiographic changes in the mobile hip when initially affected did not suggest relief of its weight bearing functions by the fused hip Far from being unburdened by the fusion of the opposite hip the mobile hip was subjected to heavy compensatory strain under both static and dynamic conditions which with time generally resulted in degenerative changes in the joint when biologically susceptible In no instance were signs of regression demonstrable

HAUGE M F (1963) Hofteankylose En röntgenologisk og klinisk studie av den ankylotiske hoftes naboledd med henblikk på anatomiske og funksjonelle forandringer Universitetsforlaget Oslo

HENRIKSSON JOHANSSON OLSSON and ÖSTLUND (1967) Electrical Analysis of the Romberg Test Acta Otolaryng Suppl 224 272-279

HERBERT J J (1960) Étude Critique Sur Les Arthrodèses De La Hance Rev Chir Orthop 46 3-14

HOHMAN D (1962) Untersuchungen zur Frage des Standbeines beim Hüftarthrodesierten Archiv für Orthop und Unfall-Chir 54 153-158

JONSSON B and STEEN B (1962) Function of the hip and thigh muscles in Romberg s test and standing at ease An electromyographic study Acta Morph Neurol Scand 5 269-276

JUDET R and JUDET J (1952) Technique and Results with the Acrylic Femoral Head Prosthesis J Bone Jt Surg 34 B 173

KARLÉN A (1944) A Clinical Study on Arthrodesis for Arthritis Deformans of the Hip Joint Acta Chir Scandinav Suppl 96

KELTON I W and WRIGHT (1949) The Mechanism of Easy Standing by Man Australian J Experim Biology 27 508 510

LINDAHL O (1965) Functional Capacity after Hip Arthrodesis Acta Orthop Scandinav 36 453-458

LINDAHL O (1965) Determination of Hip Adduction Especially in Arthrodesis Acta Orthop Scandinav 36 280-293

MACH J (1964) Die operative Hüftversteifung im Rahmen der Koxarthrosebehandlung Archiv für Orthop und Undfall-Chir 56 593-603

MACHACEK J (1956) Winkelbestimmung bei Abduktionsosteotomie am Versteiften Hüftgelenk Zeitschr Orthop 87 408 413

MAYR H (1954) Probleme und Erfahrungen an 200 Arthrodesen bei chronischen unspezifischen Hüftkrankungen Zeitschr Orthop 84 189 206

MERLE D AUBIGNE R RAMADIER J POSTEL M MAZAS F VAILLANT J (1964) L arthrodese de la hance Revue de Chirurgie Orthopedique 50 789-812

Method of Measuring and Recording American Academy Orthop Surg (1965)

PAGANI A MOROSINI C and BURATTI G (1967) A kinesiologic study of arthrodesis of the hip Europa Medicophys 3/4 265-287

V REFERENCES

ACCHIAPATI G (1962) Research on the residual work capacity in persons having had arthrodesis of the hip Archivo di Orthopedia (Milano) 75 822-8

AHLBACK, S O and LINDAHL, O (1966) Hip Arthrodesis The Connection Between Function and Position Acta Orthop Scandinav 37 77-87

ALBEE F H (1908) Arthritis deformans of the Hip A Preliminary Report of a New Operation J Amer Med Assoc I 1977-80

BECKER F (1969) Die Hüftarthrodese Rütt A Die Therapie Der Koxarthrose 274-289

BLOM G (1969) Sannolikhetsteori och statistikteori med tillämpningar Studentlitteratur Lund

CASUCCIO C (1964) Le artrodesi Trattamento Chirurgico della Coxartrosi Relatione al XLIX Congresso della Societa di Ortopedia e Traumatologica Venezia 1964

CHARNLEY J (1953) Compression Arthrodesis E & S Livingstone Ltd Edinburgh and London

DANIELSSON L G (1964) Incidence and Prognosis of Coxarthrosis Acta Ortop Scandinav Suppl Nr 66

DANIELSSON L G DYMLING J F and HERIPRET G (1964) Coxarthrosis in man studied with external counting of Sr 85 and Ca 47 Clin Orthop 31 184

DEGEL (1957) Verh dtsch Ges Orthop 44 Kongress 1956 Beiheft 88 108 (1957)

DEMIGNEUX F RAINAUT J CÉDART Cl (1968) Étude de la hance opposee aux arthrodeses Revue de Chir Orthoped 54 nr 7 649-656

DENHAM R A (1959) Hip Mechanics J Bone Jt Surg 41-B 550-557

DUCROQUET P (1965) La marche et les boiteries Études des marches normales et pathologiques Ed Masson Paris

FRANCILLON M R (1957) Zur Orthopädie der Coxarthrose Zeitschrift für *Rheumaforschung* 9 305-335

FURMAIER A (1959) Überlegungen zur Statik des Arthrodesierten Hüftgelenkes Archiv für Ortop und Unfall-Chir 51 28-36

A Coded Specification of the Material (125 cases)

Column			
1 3	Number of Case		
4	Unilateral = 1	Bilateral = 2	
5	Primary = 1	Secondary = 2	
6	Male = 1	Female = 2	
7	Pain Index = 1 3 5		
8	Increase in Radiographic Index = 1 10		
9	Frontal Position of Fused Hip =	≥ - 10 - 0	= 1
		1 - 5	= 2
		6 - 10	= 3
		≥10	= 4
10	Degree of Flexion in Fused Hip =	10 - 19	= 1
		20 - 29	= 2
		30 - 39	= 3
		40 - 49	= 4
		>50	= 5
11	Support Pattern (in percent of body weight loaded on fused leg) =	<40% f 1	= 1
		40% - 60% f 1	= 2
		>60% f 1	= 3
12	Support by Fused Leg for Two Minutes=	<40% f 1	= 1
		40% - 60% f 1	= 2
		>60% f 1	= 3
13	Support by Mobile Leg for Two Minutes =	<40% f 1	= 1
		40% - 60% f 1	= 2
		>60% f 1	= 3
14	Romberg s Test =	<40% f 1	= 1
		40% - 60% f 1	= 2
		>60% f 1	= 3
15 16	Age in Years at Follow-up		
17 18	Follow up Period in Years		
19	Radiographic Index at Follow up		

RÜTT A (1969) Die Therapie der Koxarthrose Georg Thieme Verlag Stuttgart

RYDELL N W (1966) *Forces Acting on the Femoral Head-Prosthesis* Acta Orthoped Scandinav Suppl 88

SAUNDERS M INMAN V and EBERHART H (1953) The *Major Determinants in Normal and Pathological Gait* J Bone Jt Surg 35-A 543-558

SCHEDE F (1956) Der Stand des Normalen Mechanik der Aufrechten Haltung Theoretische Grundlagen für den Bau von Kunstbeinen Zeitschr Orthop 88 Beilageheft

SEEVALD K und DEBRUNNER A M (1964) Untersuchungen über die Veränderung des nicht erkrankten Hüftgelenkes bei Hüftankylosierten Zeitschr Orthop 98 288-298

*SHEPARD M M (1954) Assessment of Function after Arthro-*plasty of the Hip J Bone Jt Surg 36-B 354-363

STEINDLER A (1955) Kinesiology of the human body C C *Thomas Springfield* Ill

STINCHFIELD F E and CAVALLERO W U (1950) Arthrodesis of the Hip Joint J Bone Jt Surg 32-A 48-58

SMITH J W (1953) Acta Orthop Scandinav 23

VERHEUGEN P et NAVARRE M (1964) La place de l arthrodese dans la chirurgie des coxarthroses *J Belge de Medicine* Physique et de Rheumatol 19, 25-32

WALMSLEY T (1933) The Vertical Axes of the Femur and their Relations A Contribution to the Study of the Erect Position J of Anatomy LXVII 284-300

WATSON-JONES R (1956) Arthrodesis of the Osteoarthritic Hip Joint J Bone Jt Surg 38-B 353-377

WEINREICH M (1960) Zur Statik der Hüftarthrodese Verh dtsch Orthop Ges 47 Kongr 509-515 (Beilagehefte)

WIBERG G (1939) Studies on Dysplastic Acetabula and Congenital Subluxation of the Hip Joint Acta Chir Scandinav Suppl LVIII

WIBERG G (1959) Hoftleden Nordisk Larobok i Ortopedi Bonniers Stockholm

Unilateral Secondary Coxarthrosis (50 Cases)

Contd
(Inflammation)

Column

1-3	4	5	6	7	8	9	10	11	12	13	14	15-16	17-18	19
091	1	2	1			2	2	1	3	1	3	49	5	0
115	1	2	1			3	2	2	3	1	1	59	8	0
124	1	2	1			4	3	1	3	1	1	44	5	0
144	1	2	1			2	2	3	3	1	2	48	7	0
151	1	2	2	1		3	3	1	3	1	1	37	4	0
145	1	2	2	1		1	3	3	3	1	2	51	4	0
158	1	2	2	1		3	3	1	3	1	2	36	7	0
034	1	2	1		1	4	3	2	3	1	1	50	11	1
072	1	2	1		1	3	2	1	2	1	1	51	4	1
104	1	2	1			1	3	1	3	1	1	19	2	0

Trauma

1-3	4	5	6	7	8	9	10	11	12	13	14	15-16	17-18	19
006	1	2	2			1	2	1	3	1	1	66	22	0
067	1	2	2			3	2	3	3	1	3	40	5	0
080	1	2	2			2	4	1	3	1	1	64	13	0
086	1	2	2			1	4	3	3	1	2	66	18	0
121	1	2	2			1	3	1	3	1	1	71	7	0
131	1	2	2			2	3	2	3	1	3	68	7	0
142	1	2	2			3	3	2	3	1	2	51	4	0
146	1	2	1			2	3	3	3	1	3	69	4	0
147	1	2	1	1		1	4	3	3	1	3	69	4	0
159	1	2	2			1	3	1	2	1	1	63	5	0
102	1	2	2			3	3	1	3	1	2	70	12	0

Unilateral Secondary Coxarthrosis (50 Cases)

Column

1-3	4	5	6	7	8	9	10	11	12	13	14	15-16	17-18	19
Developmental Disturbances														
109	1	2	2	1		2	3	1	3	1	2	74	15	0
107	1	2	2		1	2	2	1	3	1	1	60	10	1
026	1	2	2	3	3	4	4	2	3	1	2	52	19	3
037	1	2	2		1	3	4	2	3	1	2	57	6	1
059	1	2	2	1		3	4	2	3	1	2	63	18	0
089	1	2	1	1	1	1	2	2	2	1	1	77	16	1
111	1	2	2	1	3	3	3	1	3	1	2	60	5	3
155	1	2	2	3	6	2	3	1	3	1	1	63	15	6
042	1	2	2			1	4	1	3	1	2	62	8	0
029	1	2	2	3	4	3	4	2	3	1	2	58	6	4
060	1	2	2		2	3	3	2	3	1	2	61	10	2
064	1	2	2			2	3	2	2	1	2	50	9	0
079	1	2	2			2	3	1	3	1	1	52	11	0
134	1	2	2	1		4	4	1	3	1	1	46	5	0
138	1	2	2			4	4	1	3	1	2	63	7	0
013	1	2	2	1		1	2	2	3	1	1	62	16	0
016	1	2	1		2	3	2	2	3	1	2	68	20	2
062	1	2	2	1		2	3	1	3	1	1	37	13	0
110	1	2	2		1	1	4	1	3	1	1	59	11	1
004	1	2	2		2	3	4	2	3	1	2	65	22	2
118	1	2	2			3	3	2	3	1	1	44	8	0
Inflammation														
007	1	2	2	1		2	5	1	3	1	1	41	18	0
018	1	2	1		2	3	2	2	3	1	2	66	10	2
012	1	2	1			1	3	1	3	1	1	61	17	0
024	1	2	2			3	4	1	3	1	1	48	16	0
041	1	2	1	1	2	1	2	1	3	1	1	55	16	2
045	1	2	1		1	4	3	1	3	1	2	64	9	1
084	1	2	1		1	3	3	2	3	1	2	40	17	1
090	1	2	2			1	4	3	3	1	2	55	7	0

Bilateral Primary Coxarthrosis (36 Cases)

Column 1-3	4	5	6	7	8	9	10	11	12	13	14	15-16	17-18	19
001	2	1	1	3	7	1	5	3	3	1	3	62	19	9
010	2	1	1	3		2	2	1	3	1	1	60	11	5
014	2	1	2	1	6	2	4	3	8	2	2	72	23	10
017	2	1	2	3	8	4	2	2	2	2	2	72	16	9
021	2	1	2	3	2	4	3	2	3	2	2	75	10	10
022	2	1	1		6	4	2	1	2	1	1	81	15	10
023	2	1	1		1	2	1	2	3	1	2	76	14	7
025	2	1	1	1	1	4	3	2	3	1	2	69	11	4
027	2	1	1	1	5	3	2	1	2	1	1	77	19	9
031	2	1	2	3	6	3	4	2	3	2	2	70	15	8
032	2	1	1	3	4	4	2	2	3	1	2	64	5	9
043	2	1	1	5	6	2	2	3	3	1	3	63	11	7
044	2	1	1	1		2	2	3	3	1	3	71	6	8
046	2	1	1		5	1	2	2	3	1	2	60	7	6
049	2	1	2	5	3	4	2	2	3	1	2	63	11	9
052	2	1	2	1	2	2	3	1	2	1	1	75	13	4
054	2	1	1	3	1	1	4	2	3	1	2	72	8	5
055	2	1	2	3		2	3	3	3	1	3	60	6	8
061	2	1	1	5	?	1	3	3	3	2	2	74	12	6
065	2	1	2	3	5	1	3	2	2	1	1	74	10	8
069	2	1	2	1	2	1	2	2	3	1	2	60	8	5
075	2	1	1	1	1	2	3	2	3	1	2	64	7	9
082	2	1	1			2	3	2	3	1	2	61	4	5
085	2	1	1	3	3	3	3	3	3	1	3	61	10	6
088	2	1	1			1	3	2	3	1	2	56	4	3
092	2	1	1			4	3	1	3	1	1	77	3	4
093	2	1	1	1		3	2	2	3	1	2	61	3	4
094	2	1	1	3	3	4	3	2	3	1	2	65	11	6
112	2	1	2	5	2	4	3	1	2	1	1	68	14	3
117	2	1	2	3	2	4	3	2	2	1	2	66	8	8
136	2	1	2	1	1	2	4	2	3	1	2	71	3	3
137	2	1	1	5	3	1	2	3	3	1	3	65	7	8
139	2	1	2	5	1	1	2	2	3	1	2	62	7	6
148	2	1	2		1	3	3	2	3	1	2	65	6	2
150	2	1	1	5	5	3	3	2	3	1	1	61	12	7
154	2	1	2	1		3	4	1	3	1	1	72	6	2

Unilateral Primary Coxarthrosis (25 Cases)

Column

1-3	4	5	6	7	8	9	10	11	12	13	14	15-16	17-18	19
002	1	1	1	3	3	3	4	3	3	1	3	61	10	3
003	1	1	1		1	1	3	2	3	1	2	63	6	1
005	1	1	1		2	1	2	1	3	1	1	75	21	2
019	1	1	2			4	4	1	3	1	2	72	9	0
028	1	1	2		2	1	3	1	2	1	1	74	13	2
030	1	1	1		1	4	3	2	3	2	2	75	20	1
038	1	1	2			2	2	1	3	1	2	66	19	0
040	1	1	2		2	2	5	2	3	1	2	71	21	2
051	1	1	1	1	1	1	3	1	3	1	2	71	20	1
056	1	1	2			1	3	3	3	1	2	64	5	0
058	1	1	2			3	3	1	3	1	1	41	8	0
063	1	1	2	1	1	2	2	3	3	1	2	58	11	1
066	1	1	2		1	3	3	1	3	1	1	71	5	1
068	1	1	2			2	3	1	3	1	1	54	4	0
076	1	1	2			1	4	1	3	1	2	49	8	0
078	1	1	2	5	1	2	3	1	3	1	1	53	3	1
081	1	1	2	3		3	3	1	3	1	2	54	5	0
083	1	1	2	1	1	1	2	2	3	1	1	64	9	1
087	1	1	2	5		1	3	1	2	1	2	63	10	0
119	1	1	2		1	1	3	2	3	1	2	72	9	1
125	1	1	2	5	5	2	3	1	3	1	2	60	8	5
126	1	1	2	1		3	3	2	3	1	2	63	6	0
141	1	1	2	1	2	3	3	2	3	1	2	76	9	2
156	1	1	2	1		1	2	1	3	1	2	62	6	0
160	1	1	1			4	2	1	3	1	1	48	4	0

Bilateral Secondary Coxarthrosis (14 Cases)

Column

1-3	4	5	6	7	8	9	10	11	12	13	14	15-16	17-18	19
BOTH HIPS														
Developmental Disturbances														
009	2	2	2	1	1	1	3	2	3	1	2	57	14	2
035	2	2	2	3	3	4	2	2	3	1	2	59	12	8
053	2	2	2	1	2	2	2	1	3	1	1	61	7	3
098	2	2	2	1	1	3	3	2	3	1	2	42	7	4
149	2	2	2	3	4	2	1	2	3	2	2	57	6	9
108	2	2	1			1	4	2	3	2	2	60	8	8
Inflammation														
074	2	2	2	5	1	1	3	1	3	1	1	50	9	2
070	2	2	1	5	5	3	2	2	3	1	2	69	6	8
099	2	2	1	3		1	3	2	3	1	3	61	5	2
123	2	2	1	1		2	2	1	3	1	2	49	4	10
ONE HIP														
Developmental Disturbances														
133	2	2	2	1	2	1	3	3	3	1	3	63	7	3
153	2	2	1		1	3	2	2	3	1	1	71	10	5
Trauma														
116	2	2	2	3		4	3	1	3	2	1	84	10	3
036	2	2	1	1		2	2	2	3	1	2	55	14	1



1956



1958



1968

Fig 11

Case 83 Unilateral Primary Coxarthrosis

Female, aged 64 years at follow-up

1956 Pain in right hip at 52 years of age Moderate arthrosis of rigth hip Left hip normal

1958 Year of operation Rapid progress with increasing pain in rigth hip *Left hip normal*

1968 Ten years postoperatively Incipient arthrosis of left hip Radiographic index 1 Pain index 1

BJORN TIBELL

PERIPHERAL ARTERIAL INSUFFICIENCY

AN EPIDEMIOLOGICAL STUDY OF 2243 HOSPITAL ADMISSIONS CAUSED BY ARTERIOSCLEROSIS OBLITERANS DIABETES MELLITUS THROMBANGIITIS OBLITERANS AND ARTERIAL EMBOLISM

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ACTA ORTHOPAEDICA SCANDINAVICA SUPPLEMENTUM NO 139

FROM THE DEPARTMENT OF ORTHOPAEDIC SURGERY
(HEAD PROFESSOR A HULTH M D) MALMO GENERAL HOSPITAL,
UNIVERSITY OF LUND MALMO

PERIPHERAL ARTERIAL INSUFFICIENCY

AN EPIDEMIOLOGICAL STUDY OF 2,243 HOSPITAL ADMISSIONS CAUSED BY ARTERIOSCLEROSIS OBLITERANS DIABETES MELLITUS THROMBANGITIS OBLITERANS AND ARTERIAL EMBOLISM

BY

BJORN TIBELL

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Also, arterial changes in conjunction with diabetes mellitus have been studied and KRAMER and PERILSTEIN (1958) claimed that these conditions have increased between 1921 and 1956. On the other hand BELL (1957) found that the incidence of gangrene in diabetes mellitus decreased during the first half of this century.

It has been suspected that the true incidence of arteriosclerotic changes in the lower limbs is increasing. In the Department of Orthopaedic Surgery in the General Hospital, Malmö, the proportion of patients treated for peripheral arterial insufficiency as well as the number of beds occupied by these cases have increased.

However, this is not sufficient evidence of a true increase in the incidence of this disease. All hospital facilities in the city as well as changes in the distribution of the population at risk would have to be included in a survey of incidence changes. Malmö has previously proved to be suitable for epidemiological studies as demonstrated by BIÖRCK (1955), HALL (1961), SIEVERS (1963), ALFFRAM and BAUER (1962), ALFFRAM (1964), BERGE

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(1967) and STERNBY (1968) dealing with problems ranging from rheumatic fever and coronary disease to fractures, cancer and atherosclerosis.

The objective of the present study was to calculate age and sex specific incidence for the major groups of conditions leading to peripheral arterial insufficiency and to study possible changes over a 17-year period. Against the background of the hospital facilities in the city it should also be possible to estimate some socio-economic implications of this group of diseases.

MATERIAL AND METHODS

THE CITY OF MALMÖ

The city of Malmö, the third in population in Sweden, is a center of industry and trade. From the end of 1948 to the end of 1965 the population increased from 185,947 to 249,161,[1] the increase being comparatively steady over the years (Table 1).

Table 1. *The population of Malmö 1948–1965.*

	Men	Women	Total
1948	87,635	98,312	185,947
1949	89,298	99,934	189,232
1950	91,111	100,672	191,783
1951	93,572	102,918	196,490
1952	94,807	103,838	198,645
1953	96,404	105,535	201,939
1954	98,282	107,358	205,640
1955	100,301	109,172	209,473
1956	102,358	110,902	213,260
1957	104,429	112,901	217,330
1958	106,622	115,078	221,700
1959	108,685	116,975	225,660
1960	110,473	118,775	229,248
1961	112,708	120,644	233,352
1962	114,890	122,627	237,517
1963	117,140	124,638	241,778
1964	118,930	126,873	245,803
1965	120,757	128,404	249,161

During these 17 years population census was carried out in 1950, 1960 and 1965. The distribution of age and sex in the population in these three surveys is shown in Table 2.

[1] Department of Statistics, Financial Committee of Malmö.

Table 2. *Age and sex distribution of the population of Malmö.*

Age	1950 Men	Women	Total	1960 Men	Women	Total	1965 Men	Women	Total
0– 4	8,151	7,876	16,027	7,832	7,411	15,243	8,622	8,246	16,868
5– 9	7,837	7,576	15,413	7,894	7,469	15,363	7,991	7,579	15,570
10–14	5,431	5,326	10,757	8,630	8,362	16,992	8,142	7,666	15,808
15–19	4,697	4,964	9,661	8,757	8,609	17,366	9,298	9,365	18,663
20–24	6,134	6,954	13,088	7,389	7,807	15,196	10,776	10,852	21,628
25–29	7,791	8,493	16,284	7,194	7,396	14,590	8,995	8,365	17,360
30–34	8,140	8,542	16,682	7,979	7,978	15,957	7,659	7,456	15,115
35–39	8,070	8,658	16,728	8,553	8,953	17,506	8,173	8,183	16,356
40–44	7,734	8,632	16,366	8,614	8,951	17,565	8,855	9,258	18,113
45–49	6,451	7,337	13,788	8,276	8,894	17,170	8,741	9,166	17,907
50–54	5,397	6,237	11,634	7,782	8,737	16,519	8,351	8,976	17,327
55–59	4,324	5,382	9,706	6,299	7,338	13,637	7,644	8,709	16,353
60–64	3,829	4,848	8,677	4,957	6,073	11,030	5,916	7,278	13,194
65–69	3,241	4,135	7,376	3,733	4,989	8,722	4,422	5,829	10,251
70–74	2,254	3,126	5,380	2,889	4,171	7,060	3,069	4,575	7,644
75–79	1,302	1,762	3,064	2,038	2,914	4,952	2,125	3,484	5,609
80–	770	1,267	2,037	1,497	2,513	4,010	1,812	3,241	5,053
Total	91,553	101,115	192,668	110,313	118,565	228,878	120,591	128,228	248,819*
0–24	32,250	32,696	64,946	40,502	39,658	80,160	44,829	43,708	88,537
25–44	31,735	34,325	66,060	32,340	33,278	65,618	33,682	33,262	66,944
45–	27,568	34,094	61,662	37,471	45,629	83,100	42,080	51,258	93,338

* Disagreements with Table 1 depend on the differences of the dates of calculation.

HOSPITAL FACILITIES

In the city of Malmö almost all hospital facilities are owned by the community and financed by city and state funds including the compulsory state health insurance. On the whole, there are very few private or voluntary hospitals in Sweden and these only in the large cities. In the city of Malmö there are two private nursing homes with altogether 37 beds and facilities for the care of simple cases of chronic disease.

Hospitalization is free of charge except for the care of chronic somatic disease where after six months of hospitalization a small sum, well within the limits of the general pension, is charged.

The city constitutes a defined area for health care with a central administration for the three municipal hospitals: Malmö Allmänna Sjukhus (MAS) for mainly emergency and short time somatic disease, Värnhems Sjukhus (VÄS) for chronic somatic disease, and Malmö Östra Sjukhus (MÖS) for mental disease. MAS is a teaching hospital affiliated to the

ERRATA

Page 15 Previous studies:	Line 3: Bugár-Mészáros
Page 22 " "	Line 9: (1959) should be (1959 and 1960)
" "	Line 12: 561 should be 571
" "	Line 18: three should be nine
" "	Line 19: 69 should be 79
" "	Line 20: 45 should be 43
Page 30 " "	Line 6: 14 should be 13
Page 33	Line 32: 47 % should be 37 %
	Line 34: 40 % should be 44 %
Page 42 Method	Line 3: 1920 should be 1910

ADDITION

References

Page 50: BELL, E.T. (1952) A postmortem study of vascular disease in diabetics. Arch Path. 53:444-455.

" ": BLOOR, K. (1961) Natural history of arteriosclerosis of the lower extremities. Ann.roy. Coll. Surg. Engl. 28:36-52.

Page 52: KRAUTWALD, A. & VÖLPEL, W. (1960) Häufigkeit arterieller Durchblutungsstörungen der unteren Extremitäten in Beziehung zum Lebensalter und zur Lokalisation der Gefässobliteration. Dtsch, med. Wschr 85/35:1531-1536.

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70—74	2,254	3,126	5,380	2,889	4,171	7,060	3,069	4,575	7,644
75—79	1,302	1,762	3,064	2,038	2,914	4,952	2,125	3,484	5,609
80—	770	1,267	2,037	1,497	2,513	4,010	1,812	3,241	5,053
Total	91,553	101,115	192,668	110,313	118,565	228,878	120,591	128,228	248,819*
0—24	32,250	32,696	64,946	40,502	39,658	80,160	44,829	43,708	88,537
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Table 3. *Number of hospital beds in the city.*

	MAS		VÅS		MÖS	
	Total	per 100,000	Total	per 100,000	Total	per 100,000
1949	1,367	722	571	302	731	386
1950	1,373	716	571	298	731	381
1960	1,544	674	629	274	872	380
1965	1,631	655	682	274	837	336

University of Lund and receives patients also referred from other districts in the southern part of the country.

Over the years, the number of hospital beds decreased in relation to the population (Table 3). While the number of somatic hospital beds increased by 19 % and the number of beds for chronic somatic disease by 20 % between 1950 and 1965, the population increased by 29 %. In addition, the age distribution during the same period shifted towards higher age groups; the cases of the present study were rarely younger than 45 years at first admission and between 1950 and 1965 the number of residents over 45 increased by 51 %, as compared to 29 % in the total population.

CRITERIA

To be included in the study patients had to answer the following criteria:

a) *Hospitalization should* be caused exclusively by symptoms of peripheral arterial insufficiency in the legs.

b) The patient should have been admitted to a hospital in the city during the years 1949—1965.

c) The patient should at the time of admittance be a resident of the city.

Comment

Cases with peripheral arterial insufficiency have been admitted to the Departments of Orthopaedic Surgery, General Surgery, Internal Medicine, Dermatology and Infectious Disease at the MAS. Patients admitted to the VÅS and to the Department of Chronic Somatic Disease at the MAS have been presented under the same heading—Department of Chronic Somatic Disease. Altogether 10 patients in treatment for peripheral arterial insufficiency were discharged from somatic departments at the MAS to the MÖS where they were treated mainly because of their mental

and in some instances supported by angiography or histological examination.

d) *Arterial embolism:* Includes cases with sudden onset of symptoms of arterial occlusion in patients without previous history of symptoms of peripheral arterial insufficiency. All of these patients had a history of cardiac disease such as fibrillation or mitral stenosis, in addition, some had a history of emboli to other organs. Twelve patients in this group also had a history of diabetes mellitus but without previous symptoms of peripheral arterial insufficiency.

Arterial thrombosis was not used as a diagnosis in this study. Cases with a history of chronic peripheral arterial insufficiency with sudden impairment were included in the group of arteriosclerosis obliterans.

DATA REPRESENTATION AND STATISTICAL ANALYSIS[1]

Patients who were admitted to hospital because of symptoms of peripheral arterial insufficiency for the first time during the period covered by this study, 1949—1965, are referred to as *first admissions.* When analysing demands on hospital facilities during this period also patients admitted to hospital because of peripheral arterial insufficiency, who already before 1949 had previously been admitted to hospital for the same condition, were included.

The average population of the city for the years 1949—1965 was calculated in the following manner:

Sex-distribution and age-distribution in age-groups of five years were known from census on December 31, 1950, November 1, 1960 and November 1, 1965 and were calculated for men and women separately as follows:

	Dec. 31, 1950	Nov. 1, 1960	Nov. 1, 1965
Men 30—34	a	b	c

Average population of men 30—34 $= \frac{2a+3b+c}{6}$

The average frequency of first admissions for each age-group was obtained by dividing the number of first admissions in the group by the calculated average population and expressed as number of cases per 100,000.

The computation of the expected increase of first admissions during the

[1] Statistical adviser was professor Carl-Erik Quensel, Department of Statistics, University of Lund.

For the analysis of the data programming and computer services were provided by the city of Malmö and Data-SAAB, Linköping.

easily available which provides opportunities for cross-checking and back-checking of the history in each case. The panorama of peripheral arterial insufficiency in the legs can therefore be presented as completely as is possible in a retrospective study.

For administrative reasons the residency of the patients is an important item in the record and was therefore available and correct. Patients who had been referred from other districts in southern Sweden were not included in the study.

In many cases it was not possible to decide in retrospect whether or not irreversible gangrene had been present at the time of first admission. However, about 90 % of the arteriosclerotics had such gangrenous changes and almost all the diabetics.

CLASSIFICATION

The patients were classified in four groups:

a) *Arteriosclerosis obliterans:* Patients with symptoms of chronic peripheral arterial insufficiency without diabetes mellitus.
b) *Diabetes mellitus:* Patients with symptoms of chronic peripheral arterial insufficiency and with diabetes mellitus.
c) *Thrombangitis obliterans:* Patients with symptoms of chronic peripheral arterial insufficiency diagnosed as thrombangitis obliterans.
d) *Arterial embolism:* Patients with sudden onset of symptoms of peripheral arterial insufficiency.

Comment

a) *Arteriosclerosis obliterans:* Includes cases with a history of peripheral arterial insufficiency with a gradual onset. None of the patients in this group had diabetes at the time of first admission but in a few this condition was diagnosed later on.

b) *Diabetes mellitus:* Includes patients with the same type of symptoms as in arteriosclerosis obliterans who had or received the diagnosis of diabetes mellitus at the time of first admission. No attempt was made to differentiate between pathological changes caused by the specific diabetic microangiopathy and of arteriosclerotic changes in the large vessels of these patients, the effect of diabetes mellitus and possible concomitant arteriosclerotic disease was studied as an entity.

c) *Thrombangitis obliterans:* Includes patients who, at the time of first admission, received the diagnosis of thrombangitis obliterans. The diagnosis was mainly based on clinical criteria including age and sex (young men)

RESULTS

There were 967 first admissions,-550 men and 417 women distributed between the four diagnosis as demonstrated in Table 4.

AGE AND SEX SPECIFIC INCIDENCE

Previous studies

Dry and Hines (1941), Haimovici (1950), Kramer and Perilstein (1955 and 1958), Spaulding (1956), Bloor (1961), Schadt et al. (1961), Baddeley and Fulford (1965), Bugár-Mézáros and Bereczky (1966), Preuss et al. (1969) and Nielsen (1969) used the time of *first onset of symptoms* of peripheral vascular disease in the leg for calculation of age distribution. For the same purpose, Semple (1953), Oakley et al. (1956), Kaye et al. (1963), Gensler et al. (1965) and Haimovici (1967) used the point in time when the patients *first sought medical advice*. The age at which *manifest gangrene* occurred was used by Eliason and Wright (1926), Kramer (1932), John (1938), McLaughlin (1943), McLaughlin and Wiedman (1950), Bürger (1954) and McLaughlin and Heider (1955). —Silbert and Haimovici (1950), Shumacker and Moore (1951), Claugus et al. (1958), Wright (1960), Hansson (1964), Bradham and Smoak (1965), Otteman and Stahlgren (1965) and Lindahl and Bolund (1969) calculated the age distribution at *amputation* in cases with peripheral arterial occlusion. Bell (1950 and 1957) calculated the age distribution of subjects with gangrene in an *autopsy* material.

The resulting age distributions have differed considerably between the authors depending on the point in the natural history of the disease chosen and the types of vascular disease included. However, also clinical materials which appear to be similar give varying results with regard to age-distribution.

John (1938) surveying the literature found that the average age at the début of diabetic gangrene varied from 51 to 70 years. Schadt et al. (1961) found that the average age at début of vascular symptoms in diabetics was 52 years and in a mixed group of patients suffering from arteriosclerosis obliterans and diabetes mellitus 56 for men and 61 for women. On the whole, the majority of patients with peripheral arterial disease in

years 1949—1965 because of the changes in number and the shift towards higher ages in the population was made from the known distributions of 1950, 1960 and 1965.

For significance test standard statistical methods have been used, levels of probability of 99 % or better have been referred to as significant.

In order to study what changes have occurred during the 17 years covered by the study the period has been divided into three intervals 1949—1954, 1955—1960 and 1961—1965.

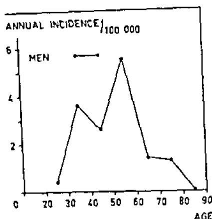


Fig. 2
Age and sex specific incidence of thrombangitis obliterans.

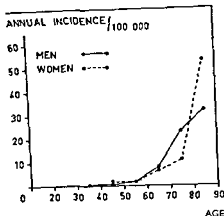


Fig. 3
Age and sex specific incidence of arterial embolism.

of the period. In diabetes mellitus some border-line significant fluctuations were observed but no consistent tendency.

Cases with arterial embolism were significantly older in the later part of the period, men as well as women.

For arteriosclerosis obliterans there was an increasing incidence throughout life in both sexes, the raise in incidence occurred about 10 years later in life in women as compared to men (Figure 1). In the diabetics there was no sex difference and the incidence did not increase further after the eighth decade.

The data on the incidence of thrombangitis obliterans and arterial embolism (Figures 2 and 3) do not permit comparison between groups or sexes. However, the deviation in the incidence pattern of thrombangitis obliterans is obvious.

These data have been calculated and presented without regard to possible changes over the years. As demonstrated below there have been considerable changes in the incidence of peripheral arterial insufficiency.

In Figures 4—10 the observed numbers per year, sex and diagnosis have been presented graphically and related to the change expected from changes in the population. It was found that in men with arteriosclerosis obliterans the observed numbers increased over the years considerably more than could be predicted from the expected values. The same, although to a less degree, was found in arteriosclerotic women. In diabetes mellitus

Table 6. *Age at first admission* (Average ±SD).

		1949–1954	1955–1960	1961–1965	1949–1965
Arteriosclerosis	Men	69±11	67±12	68±12	68±12
obliterans	Women	73± 9	75± 9	79±10	76±10
Diabetes	Men	67± 8	70± 8	67±11	68±10
mellitus	Women	68± 8	68±10	71± 7	69± 9
Thrombangitis	Men	47±12	50±10	39± 3	47±11
obliterans	Women	–	–	–	–
Arterial	Men	64±13	66±10	74±10	68±12
embolism	Women	63±10	70±13	76± 9	72±13

In the present study women with arteriosclerosis obliterans were on the average eight years older than men with the same disease. The difference was significant (Table 6). In cases with diabetes mellitus and in cases with arterial embolism there was no significant difference between the sexes.

Women with arteriosclerosis obliterans were on the average seven years older than women with diabetes mellitus, the difference was significant.

Over the 17 years covered by the study there was no significant change in age at the time of the first admission in men with arteriosclerosis obliterans. Women with this disease were significantly older during the later part

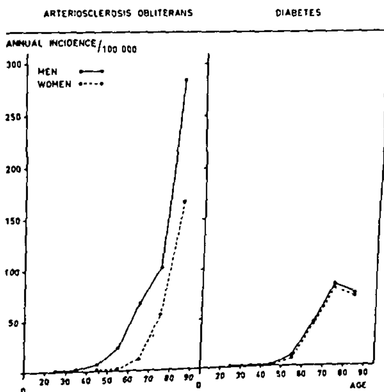


Fig. 1
Age and sex specific incidence of arteriosclerosis obliterans and diabetes mellitus admitted because of peripheral arterial insufficiency in the legs.

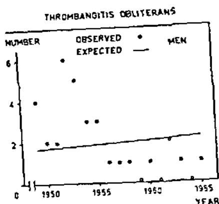


Fig. 8
Comparison between expected and observed numbers of cases of men with thrombangitis obliterans.

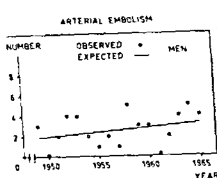


Fig. 9
Comparison between expected and observed numbers of cases of men with arterial embolism.

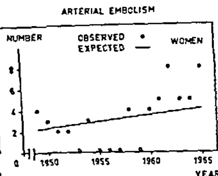


Fig. 10
Comparison between expected and observed numbers of cases of women with arterial embolism.

Comment

Peripheral arterial insufficiency has increased in rate in the city and the increase exceeds the increase expected from changes in the population. The increase was most marked although not entirely confined to arteriosclerosis obliterans so that this disease has become the most common in the group, although diabetes mellitus previously has been considered to be, and—during the early part of this study was—the most important condition causing arterial disease in the legs.

During the time of this investigation Enos et al. (1953) demonstrated

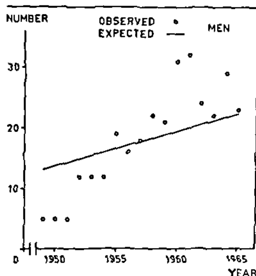


Fig. 4
Comparison between expected and observed numbers of cases of men with arteriosclerosis obliterans.

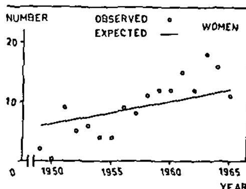


Fig. 5
Comparison between expected and observed numbers of cases of women with arteriosclerosis obliterans.

*a similar tendency was found for men but considerably less than in arterio-*sclerosis obliterans. In diabetic women the observed number agreed with the expected. Thrombangitis obliterans became a less common diagnosis over the years. The observed rate of men with arterial embolism agreed with the expected number, in women the observed number seemed to increase somewhat above the expected.

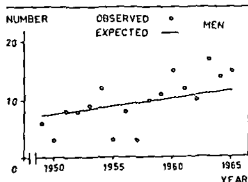


Fig. 6
Comparison between expected and observed numbers of cases of men with diabetes mellitus.

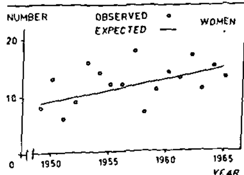


Fig. 7
Comparison between expected and observed numbers of cases of women with diabetes mellitus.

Table 7. Left–right localization at the first admission.

	Right	Left	Bilateral	Total	Unknown
Arteriosclerosis obliterans					
Men	101	125	81	307	1
Women	58	60	31	149	5
Total	159	185	112	456	6
Diabetes mellitus					
Men	69	60	34	163	1
Women	93	89	26	208	1
Total	162	149	60	371	2
Thrombangitis obliterans					
Men	10	11	12	33	
Women	0	0	1	1	
Total	10	11	13	34	
Arterial embolism					
Men	18	20	6	44	1
Women	16	33	3	52	1
Total	34	53	9	96	2
Total	365	398	194	957	10

significant preponderance for left-side affection. These independent observations taken together probably indicate a true preponderance for left-side onset in these conditions.

INVOLVEMENT OF THE CONTRA-LATERAL LIMB

Previous studies

Hasse (1959) found a bilateral onset of claudication in 18 % of his cases, *within one year 61 %* had *bilateral* claudication, within two years 76 % and within five years 92 %.

In an autopsy material Bell (1957) found bilateral cases in 21 % with *arteriosclerotic* gangrene and in 26 % with diabetic gangrene. In bilaterally amputated cases the interval between the amputations had varied between one month and seven years. Carney and Goldowsky (1957) found that the average interval between amputations because of gangrene was 1,5 years. Ottemán and Stahlgren (1965) found the same interval to be on the average 2,5 years.

Baddeley and Fulford (1965) found that one fifth of unilaterally amputated diabetics within three years had been amputated on the contralateral leg.

Russek (1966) found the average interval between the two amputations in bilaterally amputated diabetics to be 21 months.

that arteriosclerosis occurred in men as young as 20 years of age. Some of the young patients with the diagnosis of thrombangitis obliterans during the first years of this investigation may thus have been young arteriosclerotics. The changes in age and incidence over the years for these patients seem to support this hypothesis.

LEFT—RIGHT VARIATION

Previous studies

The pathological changes in these conditions usually are bilateral, even if signs or symptoms of the disease usually become obvious in one limb before the other.

Hasse (1959) found in a series of 1,406 men with claudication onset of symptoms on the left side in 44 %, on the right side in 38 % and bilateral in 18 %, there being no marked side difference. Nor could the same author find any left or right preponderance for arterial occlusion or for the first sign of gangrene.

Krautwald and Völpel (1959) presented 722 patients with various symptoms of arterial insufficiency in the legs, nine per cent of whom were women. There were symptoms from altogether 1,166 legs, 595 left legs and 561 right legs. The difference was not significant.

Kaye et al. (1963) found in a series of arteriographies of 269 patients with arterial insufficiency no side difference neither with regard to occlusion nor to atheromatos lesions.

Eliason and Wright (1926) found in 100 cases of gangrene of the legs in arteriosclerotic and diabetic patients right side affection in 46, left side in 45 and bilateral in three.

Wessler et al. (1958) found in 75 patients with 69 episodes of arterial embolism in the legs 45 left-sided and 28 right-sided affections, eight were located in the bifurcation.

Present study

In 957 first admissions in the present study the left—right localization was clearly stated. There were 365 cases right-sided, 398 left-sided and 194 bilateral cases (Table 7). There were no significant differences between sexes, between the four diagnostic groups or in the total material.

Comment

It should be noticed that in the majority of the data presented in medical literature as well as in the present study there is a slight but usually not

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Women	*0*	*0*	*1*	1	
Total	10	11	13	34	
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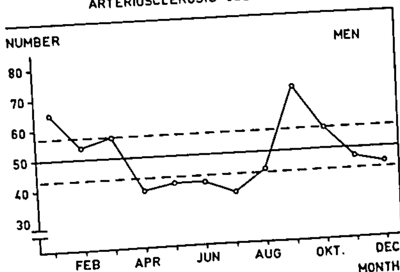


Fig. 12
Seasonal variation of admissions for men with arteriosclerosis obliterans.

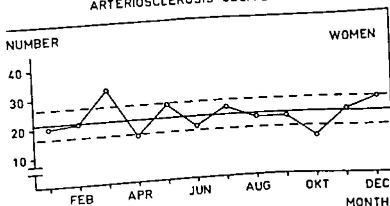


Fig. 13
Seasonal variation of admissions for women with arteriosclerosis obliterans.

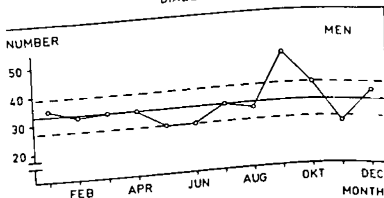


Fig. 14
Seasonal variation of admissions for men with diabetes mellitus.

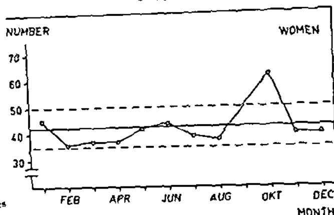


Fig 15.
Seasonal variation of admissions for women with diabetes mellitus.

Comment

There is a tendency of seasonal variation characterized by a decreased incidence in the spring and in the summer. This variation is more pronounced for men and somewhat more in arteriosclerosis obliterans than in diabetes mellitus. However, the variation usually does not reach a level of significance which permits statistical comparisons between the subsets. In thrombangitis obliterans and arterial embolism no pattern of seasonal variation could be distinguished.

The time lag between onset of symptoms *or impairment and admission* may vary considerably, and therefore the first admission should probably not be regarded as a biological parameter reflecting a true seasonal variation of the disease.

AGE AT DEBUT OF DIABETES MELLITUS

Previous studies

Although diabetes may be diagnosed at any age the début in most patients is between 40 and 70. Spiegelmann and Marks (1946), Pyke (1956), Buschmann et al. (1958), Schliack (1959) and Jung et al. (1968) published somewhat varying figures with respect to the onset of diabetes but all agreed that onset of the disease usually occurred in the *middle-aged*.

Data derived from authors who have presented their age distribution in age groups are presented in Table 9 and 10.

Oakley and Cohen (1954—1955) and Goldner (1960) did not find a single case in which the diabetes had originated before the age of 20 among their patients with peripheral vascular disease of the lower limb.

Table 9. *Age at début of diabetes mellitus, per cent of the patients.*

Authors	Observa- tion period	No.	Age at debut of diabetes mellitus 0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80+
Pavy	<1885	1,352		4	7	17	25	31	13	3 (70+)	
Pincus, Joslin & White	1898–1933	9,853	5	7	8	12	23	27	18 (60+)		
John	1921–1948	6,000	5	4	6	12	23	27	23 (60+)		
Bell	1910–1951	1,559	1	4	5	6	15	27	26	13	3
Silwer	1954	1,326	6	8	6	8	13	25	23	9	1
Fitz-gerald	1949–1958	5,441	2	4	5	6	13	26	28	14	1
Hansson	1947–1956+1961	143		1 (<30)		2	11	29	31	20	2 (+4 unknown)
Tibell	1949–1965	373	1	1	1	4	15	23	34	18	3

Among 3,500 cases of arterial occlusion in the legs DeBakey et al. (1964) found only six patients with juvenile diabetes.

Present study

The percentual distribution of age at onset of diabetes in individuals who had their first admission during the years 1949 to 1965 are presented in Table 9 and compared to a series of individuals amputated because of diabetic gangrene (Hansson 1964) and to data presented by other authors on individuals about whom it is not known whether they had developed vascular complications or not. There was a significant tendency of higher ages in the present series as compared to the other series with one exception, Hansson (1964), who also dealt with cases of vascular complications in the lower limbs. In Table 10 the data of the present study are compared with respect to age distribution within the sexes and to similar data in diabetics without known vascular complication. The differences between the sexes in age at onset of diabetes were not consistent. In the present study the women had been significantly older at the time of onset of diabetes than had the men (Table 11). There was no change in this respect between the three periods of the study.

Table 10. *Age at début of diabetes mellitus in men and women, per cent of the patients.*

Authors	Observation period	No	Sex	Age at dèbut of diabetes mellitus 0–9	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80+
Pavy	<1885	963	Men		4	7	16	27	29	14	3 (70+)	
		389	Women		6	7	18	20	35	11	2 (70+)	
Pincus, Joslin & White	1898–1933	4,639	Men	5	7	10	14	23	24	14	3 (70+)	
		5,214	Women	4	6	6	11	23	30	16	3 (70+)	
Blumberg & Zisserman	1930–1938	52	Men	(<20.)	2	0	4	15	21	27	15	4 (12 unknown)
		103	Women	(<20)	2	4	11	13	36	27	2	0 (6 unknown)
Blumberg & Zisserman	1939–1950	80	Men	(<20)	3	3	5	15	21	19	18	1 (16 unknown)
		167	Women	(<20)	2	0	5	18	29	25	7	2 (13 unknown)
Silwer	1954	598	Men	7	10	8	12	15	21	18	9	1
		728	Women	5	6	5	5	12	29	28	10	1
Fitzgerald	1949–1958	2,181	Men	3	5	7	9	16	24	23	11	1
		3,260	Women	1	3	3	4	11	28	32	16	1
Tibell	1949–1965	164	Men	0	1	2	7	17	26	30	15	2 (1 unknown)
		209	Women	1	1	1	2	13	20	37	21	4 (1 unknown)

Comment

The study of Hansson and the present study differ from the other studies with respect to the proportion of patients with début of diabetes mellitus before the age of 40. The former studies include only amputated patients and patients admitted to hospital because of symptoms of peripheral arterial insufficiency, the latter are based on diabetics without special reference to peripheral vascular disease. The difference is due to the small number of juvenile diabetics among cases with peripheral vascular complica-

Table 11. *Age at onset of diabetes mellitus* (Average ± SD).

	1949–1954	1955–1960	1961–1965	1949–1965
Men	55±11	56±13	56±14	55±13
Women	59±12	58±14	60±11	59±13

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Table 12 *Time-lag between the diagnosis of diabetes mellitus and severe symptoms of peripheral vascular insufficiency.*
(Per cent of patients, the bars indicate the time intervals used by the authors).

Authors	Observation period	No.	Years 0		1	2	3	4	5	10	15	20	25	30 >30	• Unknown
McLaughlin & Heider	1932 1953	135	13	10	9	16			21	32					0
Kramer & Perlstein	1942–1956	859	15	12	37				19	8	6	3			0
Root & al.	1954	502	8		18				38		30			2	4
Oakley & al	1950 1953	146	14		18				20	17	18	14			0
Scheibe & Gallenkamp	1952–1965	66	14	21					9	18	6	18			14
Viskum	1961–1967	157	21		17				28		34				0
Goldner & al.	1957–1958	71	17	23					24	17		13		3	4
Hansson	1947–1956 +1961	143	11		31				15	17	12	10			4
Tibell	1919–1965	373	20	0	3	5	6	3	19	17	12	7	4	2	1

tion. In the series of Hansson and in the present series 82 and 78 per cent of the patients, respectively, were over 50 at the début of diabetes mellitus as compared to 58 % in the series of Silwer.

TIME-LAG BETWEEN THE DIAGNOSIS OF DIABETES MELLITUS AND FIRST ADMISSION FOR PERIPHERAL ARTERIAL INSUFFICIENCY

Previous studies

Conway and Meigher (1942) found an average interval of eight years between the début of diabetes and the first signs of vascular foot lesion and in 20 % of the cases the diabetes was not diagnosed prior to the occurrence of vascular symptoms. Block and Whitehouse (1963) calculated the same variable to be 12,5 years, Bryfogle and Bradley (1957) to 14 years and Hansson (1964) to nine years. Authors who have presented the time intervals as distributions are referred to in Table 12.

Baddeley and Fulford (1965) found in a series of amputated diabetics that in 39 % the diagnosis of diabetes had been made one year or less before the operation. Bartels and Rullo (1958) found in patients with symptoms of peripheral arterial insufficiency without previously known diabetes that only 23 % had completely normal glucose-tolerance tests and 20 % were diabetics. Joslin (1934) found that patients with diabetes who died with gangrene in the lower limb on the average had had their diabetes for 10 years.

Present study

In the present study the average interval between the début of diabetes and the first admission was 9,6 years, 10,7 for men and 8,7 for women, significantly shorter for women. The time variable was skewedly distributed and is presented in Figure 16. Table 12 presents a comparison between the present series and previous studies in this respect. In 20 % of the cases in the present series the diagnosis of diabetes had not been made prior to the first admission which is one of the highest fractions observed.

Comment

The sampling process is not uniformly defined in the studies listed in Table 12 but include various stages of arterial insufficiency. Viskum (1969) dealt with cases of manifest gangrene. Goldner et al. (1959) and Hansson (1964) described amputated diabetics. Only in the present study the first admission because of peripheral arterial insufficiency was used to

Starting from the *début of symptoms* of peripheral arterial insufficiency SILBERT and ZAZEELA (1958) found that the 10-year survival for diabetics was 62 % and for non-diabetics 89 %, the mortality was particularly increased in diabetics between 40 and 50, while in the same age-group of non-diabetic patients, the survival did not differ from that of the base population.

Using the *first consultation* because of symptoms of peripheral arterial insufficiency HINES and BARKER (1940) found that 45 % survived for three years. BOYD and BLOOR (1959) had a five year survival of 74 %, a 10 year survival of 39 % and 15 year survival of 22 %.

In cases with femuro-popliteal occlusions verified by *angiography* SINGER and ROB (1960) had a five year survival of 84 %. For patients with aorto-iliacal occlusion the figure was 69 %.

Calculated from the *time of the diagnosis* JUERGENS, BARKER and HINES (1960) found that in cases of femuro-arterial occlusion caused by arteriosclerosis obliterans the five year survival was 80 % and the 10 year survival 57 %, for aorto-iliacal occlusion the figures were 73 and 47 respectively.

In *gangrene* HEINE and SCHMIDT (1966) found a survival of 27 % after four and a half years.

FAXON (1939) found in patients with *peripheral arterial insufficiency* a five year survival of 38 % in arteriosclerosis obliterans, 39 % in diabetes mellitus and 85 % in thrombangitis obliterans. MAZET (1967) published the survival rates for diabetics and non-diabetics sampled from several hospitals. Most findings are in agreement with the statement by SKVERSKY and ZISLIS (1970) that "the outlook for longevity of diabetic amputees and non-diabetic amputees is similar."

SILBERT and HAIMOVICI (1950), DALE and CAPPS (1959), ROSENBERG et al. (1970) and THURSBY and DUNN (1970) all described the survival following *amputation* because of peripheral arterial insufficiency with varying results.

MCKITTRICK (1940) found 55 % survival after three years in cases with *diabetic gangrene*. After five years the figure was 47 %. SILBERT (1948) compiled the three year survival after femur *amputation* in diabetics from several hospitals to be 40 %. However, later he (SILBERT 1952) found that the figure had increased to 65 %.

Similarily, SMITH (1956), WRIGHT (1960), BLOCK and WHITEHOUSE (1963), BADDELEY and FULFORD (1965), WHITEHOUSE et al. (1968) and VISKUM (1969) have presented survival rates in cases with *diabetic gangrene* within the same order of magnitude as presented above.

WESSLER et al. (1958) in a series of *arterial embolism* found that 21 % died in hospital, and that the three year survival was about 50 %.

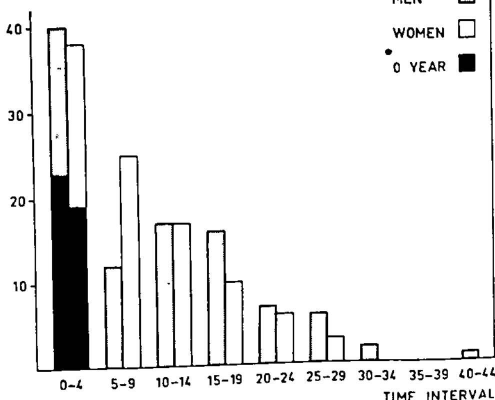


Fig. 16

Time interval between the diagnosis of diabetes mellitus and the first admission for peripheral arterial insufficiency, men and women separately, per cent of group. 0 YEAR means that the diagnosis of diabetes was unknown prior to the first admission.

terminate the time lag. The patients of this series have all reached the point when their peripheral arterial disease necessitated hospital admission. All of them were not amputated on during the first admission and the attitude to treatment of these patients has been fairly conservative and similar to that in the series of Viskum. In this and the present study there were 20 % cases of undiagnosed diabetes. Only in two other previous studies, Conway and Meigher (1942) and Baddeley and Fulford (1965), similar percentages were noted.

SURVIVAL

Previous studies

Survival has been calculated from various points in time in the natural history of peripheral arterial disease.

77 % and for women 57 %, one year survival for men 68 % and for women 45 %, three year survival for men 56 % and for women 27 % and five year survival for men 48 % and for women 24 %.

There was no difference between men and women in cases with diabetes (Figure 18). The survival at three months, one year, three years and five years were for men and for women 90 and 85 %, 73 and 69 %, 47 and 49 % and 37 and 34 %, respectively.

Except for differences between the sexes it can be seen that there were significant differences between diabetes mellitus and arteriosclerosis obliterans. Arteriosclerotic men had a longer survival than had diabetic men, arteriosclerotic women, however, had a shorter survival than had diabetic women.

In thrombangitis obliterans the survival probably did not differ from that of the population by large (Figure 19).

Cases of arterial embolism had a three months survival of only 50 % and the one year survival was the same as for arteriosclerotic women, 45 % (Figure 20). This former group of patients has been established to have a poor life expectancy mainly because of the risk of repeated emboli to other organs. (Haimovici 1950 and Wessler et al. 1958).

Comment

For part of the cases the follow-up time was less than five years. In order to compare possible changes in survival over the years and to study

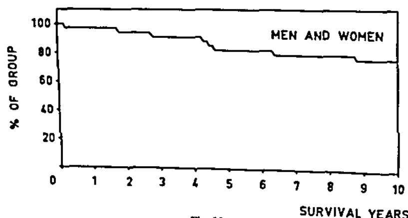


Fig. 19
Survival of patients with thrombangitis obliterans and with first admissions 1949—1965, per cent of group.

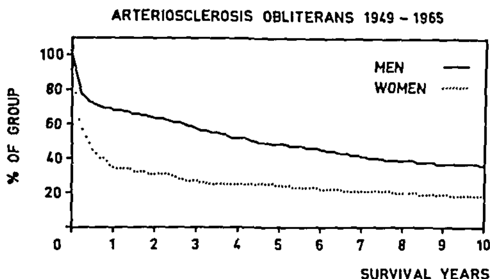


Fig. 17
Survival of men and women with arteriosclerosis obliterans and with first admissions 1949—1965, per cent of group.

PRESENT STUDY

For the purpose of studying survival, all individuals who had their first admission during 1949—1965 were followed up to at least July 31, 1967, the follow-up being complete up to that date.

In arteriosclerosis obliterans there was a considerable difference in survival between the sexes (Figure 17). Three months survival was for men

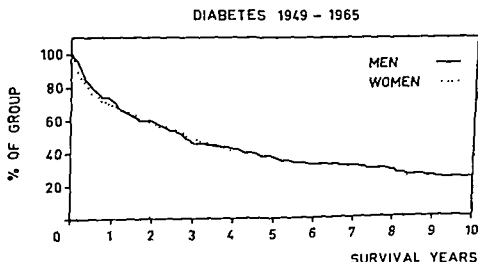


Fig. 18
Survival of men and women with diabetes mellitus and with first admissions 1949—1965, per cent of group.

77 % and for women 57 %, one year survival for men 68 % and for women 45 %, three year survival for men 56 % and for women 27 % and five year survival for men 48 % and for women 24 %.

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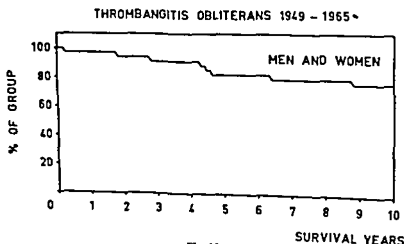


Fig. 19
Survival of patients with thrombangitis obliterans and with first admissions 1949–1965, Per cent of group.

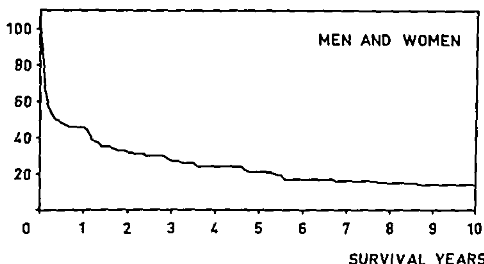


Fig. 20
Survival of patients with arterial embolism and with first admissons 1949—1965, per cent of group.

the influence of the somewhat varying follow-up time the cases of arterio-sclerosis obliterans and diabetes mellitus were sub-divided in three groups according to their first admissions: 1949—1954, 1955—1960 and 1961—1965 (Figures 21 and 22). *The difference between arteriosclerotics and diabetics was fairly permanent over the years.* In the arteriosclerotics the

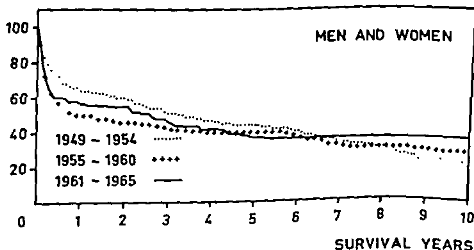


Fig. 21
Survival of patients with arteriosclerosis obliterans and with first admissions 1949—1954, 1955—1960, 1961—1965, per cent of group.

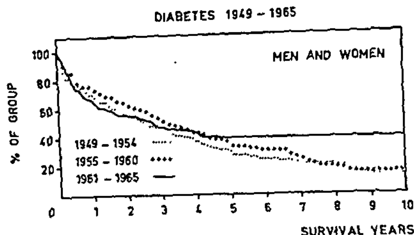


Fig. 22
Survival of patients with diabetes mellitus and with first admissions 1949—1954, 1955—1960, 1961—1965, per cent of group.

death rate in the first months was comparatively high, but from there on the mortality curve flattens out more than in the diabetics. This difference between the diagnoses was most pronounced in women (Figures 17 and 18, p. 31). The short survival of arteriosclerotic women as compared to men is explained by the age-dependent decrease in life expectancy. The women who died within one year after the first admission were five years older than the average age for arteriosclerotic women.

DEMANDS ON HOSPITAL FACILITIES

Previous studies

The average length of hospital stay for patients admitted because of symptoms of peripheral arterial disease in diabetics or arteriosclerotics has been presented by several authors, Eliason and Wright (1926), McKittrick (1940), McLaughlin and Heider (1955), Root et al. (1955), Carney and Goldowsky (1957), Caine et al. (1967), Warren and Kihn (1968). In these studies only one admission is recorded for each patient and the average length of stay varies between 23 and 206 days depending on factors such as the selection of cases, the level of amputation and the rehabilitating resources. Cameron et al. (1964) in a series of 47 diabetic patients with 67 admissions because of amputation found an average length of stay of 65 days and a total of time spent in hospital after amputa-

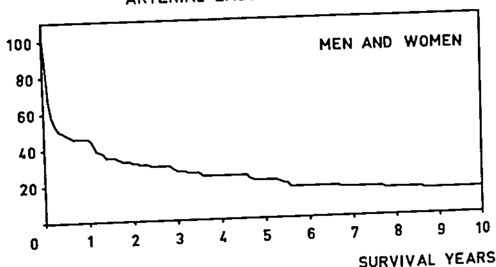


Fig. 20
Survival of patients with arterial embolism and with first admissons 1949—1965, per cent of group.

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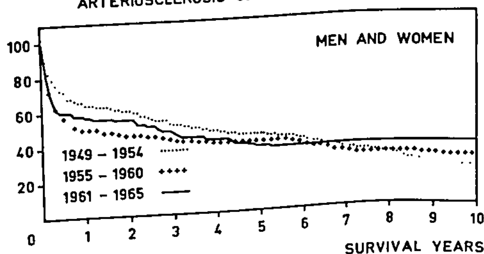


Fig. 21
Survival of patients with arteriosclerosis obliterans and with first admissions 1949—1954, 1955—1960, 1961—1965, per cent of group.

Table 13. *Hospital days per admission.*

	Departments of somatic diseases	Department of Chronic Somatic Disease
Arteriosclerosis obliterans		
Men	42	119
Women	50	122
Diabetes mellitus		
Men	55	146
Women	58	141
Thrombangitis obliterans		
Men	33	104
Women	48	—
Arterial embolism		
Men	25	81
Women	37	69

In Table 13 is demonstrated the average time of each hospitalization in days during 1949—1965. Sex, diagnosis and for the departments of somatic disease respectively Chronic Somatic Disease, are presented separately. For each single admission, diabetics were hospitalized longer

Table 14. *Destination at discharge from first admission, per cent of group.*

	Destination Home	Departments of somatic diseases	Home for the aged or convalescent	Departments of Chronic Somatic Disease	Dead
Arteriosclerosis obliterans					
Men	59	15	4	6	16
Women	28	20	1	9	42
Diabetes mellitus					
Men	57	20	2	10	12
Women	52	24	2	7	14
Thrombangitis obliterans					
Men	67	27	3	3	0
Arterial embolism					
Men	33	31	4	2	29
Women	30	25	2	6	38
Total series					
Men	57	19	3	7	15
Women	41	22	2	8	27
Men + Women	50	20	3	7	20

tion of 89 days. Sixteen patients who died in hospital after amputation were not included. VISKUM (1969), reviewing a conservatively treated series of diabetic gangrene with an average observation time of 3,8 years found the average length of initial stay in hospital to be 77 days and a total average hospital stay for each patient of 146 days.

There are no studies presented demonstrating the annual or accumulated number of days in hospital for patients with peripheral arterial insufficiency in a defined population at risk. Nor are data available on possible changes with time of the demands on hospital facilities.

PRESENT STUDY

In the calculation of the demands on hospital facilities from patients with peripheral arterial insufficiency all 2,243 admissions over the period were used. This also included 89 patients who had been admitted for the *first time before* 1949.

For the patients in these complete series the annual demand for hospital days was more than tripled during the time under study (Figure 23). During the same time the population of the city increased by one third.

The changes in different groups were in accordance with changes in incidence.

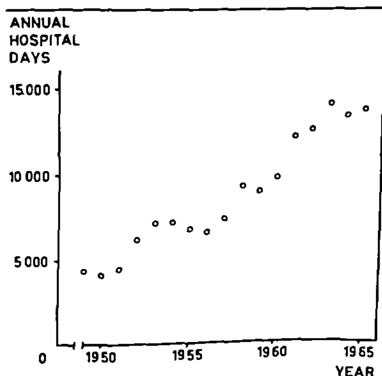


Fig. 23
Days in hospital required annually by patients with peripheral arterial insufficiency.

hospital days as compared to 1,96 % in 1965. Again, this points out that the number of patients was tripled and the number of hospital beds available largely unchanged: with an increase in the population 1949—1965 by one third went a 200 % increase of the hospital beds needed by these patients.

To some extent the demands for hospital beds for this category of patients may be related to survival. There was, however, not sufficient change in the rate of survival of these patients to explain the change in the need for hospital beds. Also patients with comparatively short survival rates such as the arteriosclerotic women did not as a group accumulate fewer hospital days over the years than arteriosclerotic men with a better short time survival. Men with diabetes mellitus had a survival very similar to women but accumulated over the years about 50 % more hospital days than the women (Table 16).

Table 15. *Annual hospital days for patients with peripheral arterial insufficiency in relation to all available and per 100,000 inhabitants.*

Year	Total number	%	Number per 100,000 inhabitants
1949	4,400/645,796	=0,68	2,380
1965	13,750/700,592	=1,96	5,520

than arteriosclerotics or the other groups. Men had shorter admissions in all groups in the somatic departments but not in the chronic somatic departments.

During 1949—1965 totally 960 patients were discharged from their first admission (Table 14). About half of these patients could return to their homes, and in addition a few per cent were discharged to homes for the aged or for convalescents. One fifth were discharged to other somatic departments. About seven per cent were directly transferred to the Department of Chronic Somatic Disease, a rather small number considering the fact that this department becomes the end station for so many of these patients. One fifth of the patients died during the first admission.

There was an obvious sex difference in cases with arteriosclerosis obliterans. Considerably fewer women could return to their homes and more than 40 % died.

COMMENT

The increase in incidence found in the present study may also be put in relation to the total hospital facilities (Table 15). The total requirement of hospital days for patients of this kind was in 1949 0,68 % of the available

Table 16. *Average accumulated number of hospital days per patient.*

	Men	Women
Arteriosclerosis obliterans	104	137
Diabetes mellitus	214	139
Thrombangitis obliterans	103	48
Arterial embolism	63	57

Systematic changes in the indications for hospital admission over the years could not be demonstrated. No new therapeutic measures have changed the indications for hospitalization. The attitude towards vascular surgery has been very restricted in Malmö. The number of hospital beds available decreased in relation to the population. The duration of each hospitalization did not increase.

These findings indicate indirectly that no major changes in the attitude towards hospitalization of these cases have taken place.

ASPECTS ON ARTERIOSCLEROSIS

The most prominent finding in the present study was the increase in incidence of arteriosclerosis obliterans in the lower limb in men. In the same population STERNBY (1968) found in autopsies that arteriosclerotic changes were observed earlier in life and also were more common in men than in women. In clinical materials including cases amputated because of arterial insufficiency several investigators (CARNEY and GOLDOWSKY 1957, ALFFRAM and HOLMQUIST 1961, PERLOW 1962, GENSLER et al. 1965, MITTY and ALMEDA 1967, HAIMOVICI 1967) found that the diabetics constituted half or more of their respective cases. In the early years of the present study diabetes was the most important condition in the group of disease causing peripheral vascular insufficiency, but later on, arteriosclerosis became the overwhelmingly most important. In the same population, the city of Malmö, SIEVERS (1963) presented data concerning myocardial infarction. In comparison to arteriosclerosis of the lower limb the incidence of myocardial infarction during an overlapping period of time did not increase appreciably. The two manifestations of arteriosclerotic disease obviously did not develop at the same rate in the population. HENSCHEN (1953) demonstrated that during the Second World War, in Sweden, when the standard of living with regard to food supply was low, the incidence of arteriosclerosis in autopsies decreased. During the time covered by the present study the standard of living, no doubt, improved. This increased standard has except for dietary habits also changed the means of transportation. So have for instance private automobiles become nine times as common. In the meantime the hospital facilities of the city have remained largely unchanged and, in relation to the population, decreased. During the time covered by this study no curative treatment of arteriosclerosis was introduced.

Similar changes are taking place or will take place in other communities

DISCUSSION

METHOD

The incidence of gangrene in diabetics and non-diabetics was calculated by Bell (1950) and based on more than 40,000 *autopsy* records covering the years 1920—1947. This study has later been followed up and the same type of data presented for 1948—1955 (Bell 1957).

Also it has been demonstrated that peripheral vascular disease in the legs is becoming an increasingly common cause of *amputation* (Engsig-Karup 1963, Lindholm 1964 and Hansson 1964).

A good portion of these patients were diabetics and the incidence of *peripheral vascular complications in diabetes* has been investigated by Rabinowitz et al. (1934), Dry and Hines (1941), Bürger (1954), McLaughlin and Heider (1955), Mellinghoff (1955), Schneeweiss and Gassman (1955), Buschmann et al. (1958), Kramer and Perilstein (1958), Bugár-Mészáros and Bereczky (1966) and Lindahl and Bolund (1969).

Widmer et al. (1964) found *arterial occlusion* in the legs in 11 out of 1,550 women and 64 out of 4,887 men in a study of cardio-vascular disease in 6,400 drug industry employees. The study included only individuals under the age of 65. It was noticed that out of 4,826 men without arterial occlusion not less than 23 % had symptoms such as coldness or parestesia from the legs, although, out of the 64 men with occlusion 30 % were free of symptoms. Obviously, it is difficult to separate pathological conditions in the peripheral arteries from these occurring with age in a majority of the population. Most of the individuals affected remain free of symptoms. In a fraction of the population there are varying degrees of dysfunction and in some instances arterial occlusion results in gangrene and even death.

For the purpose of the present study *hospital admission* because of severe signs or symptoms of peripheral arterial insufficiency has been the criterion. In the continuum of severity of arterial disease hospital admission is usually indicated at a level of severity when the patient can no longer be managed ambulatorily. At this stage the diagnosis is usually obvious.

Systematic changes in the indications for hospital admission over the years could not be demonstrated. No new therapeutic measures have changed the indications for hospitalization. The attitude towards vascular surgery has been very restricted in Malmö. The number of hospital beds available decreased in relation to the population. The duration of each hospitalization did not increase.

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Similar changes are taking place or will take place in other communities

of the world. However, it is not possible to extrapolate from the data of the present study to other types of communities or into the future without great care.

ASPECTS ON DIABETES MELLITUS

Studies on the incidence of diabetes mellitus from different parts of the world and by different authors have yielded varying results. SILWER (1958) found in a survey of 46 studies published between 1916 and 1953 a variation between 0,4 and 43 per thousand. The incidence found by Silwer in an area in the southern part of Sweden was 5,1 per thousand. The Diabetes Survey Working Party (MALINS et al. 1962) found the incidence in England and Wales to be 6,4 per thousand. The same group found that about the same frequency of previously undetected diabetes could be diagnosed in such a survey. REMEIN (1959) surveying 64 similar studies also reported that the incidence of undetected diabetes was about the same as that of known, diagnosed disease. In cases with myocardial infarction SIEVERS (1963) found that in cases which also had diabetes mellitus the latter disease in about 15 % of the cases was undetected prior to the cardiac. In the present study not less than 20 % of the cases were undiagnosed until they had been admitted to hospital because of their vascular symptoms. Values of similar magnitude have been found by other authors (Table 12, p. 31). Against the background of the high incidence of undiagnosed diabetes in the population this number is not surprising. In addition, a stress condition such as myocardial infarction or onset of severe peripheral vascular symptoms may well provoke a latent diabetes in the patient.

The risk of peripheral vascular complication in patients with diabetes has been estimated to be 2—59 % depending on the sampling procedure (CONWAY and MEIGHER 1942, BÜRGER 1954 and KRAMER and PERILSTEIN 1958). RABKIN and FIELD (1962) found that of all diabetic patients admitted to hospital about seven per cent were amputated or subjected to vascular surgery. WHITE (1956) found that out of over one thousand cases of juvenile diabetics who had survived for more than 20 years almost half eventually had developed aortic calcification and that 0,5 % had gangrene. In the present study very few of the cases could be classified as juvenile diabetics.

Data on age and sex specific incidence of diabetes in the city of Malmö are not available. However, SILWER (1958) calculated these data in an area of southern Sweden close to the city (Kristianstad), and there is at the present time no reason to believe that diabetes should have different

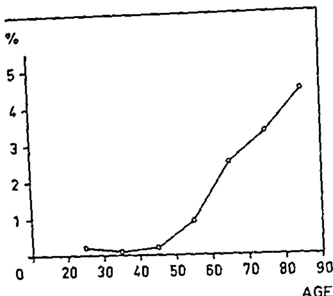


Fig. 24
Annual risk for diabetics to become admitted to hospital because of peripheral arterial insufficiency.

patterns in Malmö and other towns in southern Sweden. A projection of the incidence of peripheral vascular complications in the lower limbs on the population of diabetics combining the data of Silwer and the present study demonstrated that for septuagenarians when diabetes was most common so was the incidence of peripheral vascular complications in the legs. However, there was a significant increase of the annual incidence of peripheral vascular complication in diabetics starting in the sixth decade and increasing throughout life (Figure 24). In fact, for octogenarians the annual risk for diabetics of being admitted to hospital because of peripheral vascular insufficiency was four to five per cent.

BELL (1950) found in an autopsy material that gangrene was 40 times more frequent in diabetics as compared to non-diabetics. In the present study the annual incidence of peripheral arterial insufficiency for quinquagenarians was increased by a factor of about 30 in diabetics as compared to the population at risk. For octogenarians the annual risk of peripheral arterial insufficiency in diabetics increases considerably but at the same time the risk of arteriosclerosis in the rest of the population increases even more, so that peripheral arterial insufficiency is only eight times as frequent in diabetics. The data of Bell were obtained before 1950. Since then, as demonstrated in the present study arteriosclerosis as the cause of peripheral arterial insufficiency has become considerably more common which may explain the discrepancy between the two studies.

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study, however, it was not possible to demonstrate any significant changes in incidence over the years. On the other hand, the patients were significantly older during the later part of the period covered by this study.

SOCIO-ECONOMIC ASPECTS

McLaughlin (1943), Root et al. (1955) and Rabkin and Field (1962) presented accounting figures on the costs of hospital care of cases with diabetes and vascular complications. Diabetes was found to be a comparatively expensive disease and particularly so when vascular disease leading to amputation complicated the condition. Also, comparatively many patients needed care in nursing homes or similar institutions after discharge from hospital. In the hospitals involved in the present study the budgeting system does not permit extraction of the cost for separate patients. Basing the calculations on the average daily cost of a hospital bed and changes in the costs of living, it could be demonstrated that, in Malmö, the tripling of the hospital demands by the group of patients described above was associated with an increase of the costs, corrected for changes in the costs of living, in departments for somatic disease by nine times and in departments for chronic somatic disease by eleven times.

Integration into units for the care of cases with peripheral vascular disease, both ambulatory and hospitalized, is probably a requirement for progress in this field. The costs involved are an additional argument for an evolution along these lines.

The true incidence of peripheral vascular complication to diabetes mellitus in the city was increased only in men. KRAMER and PERILSTEIN (1958) claimed that the risk of vascular complication to diabetes increased between 1920 and 1956. The findings of these authors should be seen against the background of the increased risk for diabetic vascular complications with increasing age and the increasing survival of diabetics over the years. In the present study there was no indication that diabetic men should have a longer survival than the women. It may well be that circulatory impairment caused by the microangiopathy of diabetes mellitus remained unchanged over the years while the increased risk for men to have peripheral vascular complications to their diabetes is due to an increased risk of arteriosclerosis in these patients.

ASPECTS ON THROMBANGITIS OBLITERANS

WESSLER et al. (1960) expressed the opinion that thrombangitis obliterans, Buerger's disease, did not exist as a pathological entity. NIELSEN (1969), however, found histo-pathological evidence of thrombangits obliterans in 28 out of 448 patients with peripheral vascular insufficiency in the legs. MOZES et al. (1970) suggest that young patients with ischemic symptoms from the legs may belong to three groups, one of young arteriosclerotics, one with thrombangitis obliterans and a third with a combination of the two. In the present study it could be demonstrated that the diagnosis of thrombangitis obliterans had been less used in the later part of the period. However, there is no doubt that the diagnosis constitutes a deviating group, as they are almost all men, significantly younger than any other diagnostic group and with a survival that differs from the rest of the material.

ASPECTS ON ARTERIAL EMBOLISM

BELL (1950) found in autopsies arterial embolism in 0,14 %. In cases amputated because of peripheral arterial insufficiency the frequency of arterial embolism has been described to range from 4,5 to 9,8 % (DALE and JACOBS 1962, PERLOW 1962, HANSSON 1964 and LINDHOLM 1964). In the present study the incidence of arterial embolism was no less than 10 %. THOMPSON et al. (1970) claimed that the disease indeed increased not only because of increasing age but also because of improvements in the treatment of patients with cardiac failure. In the present

study, however, it was not possible to demonstrate any significant changes in incidence over the years. On the other hand, the patients were significantly older during the later part of the period covered by this study.

SOCIO ECONOMIC ASPECTS

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Integration into units for the care of cases with peripheral vascular disease, both ambulatory and hospitalized, is probably a requirement for progress in this field. The costs involved are an additional argument for an evolution along these lines.

SUMMARY AND CONCLUSIONS

A retrospective study was carried out on all individuals who had been admitted to hospital in the city of Malmö during the years 1949—1965 because of peripheral arterial insufficiency in their legs. The patients were classified in four main groups according to diagnosis: arteriosclerosis obliterans, diabetes mellitus, thrombangitis obliterans and arterial embolism. During this period 967 cases were admitted to hospital for the first time and from observations on these patients the following conclusions were made:

Women with arteriosclerosis obliterans were on the average eight years older than men and seven years older than men or women with diabetes mellitus. The age at first hospital admission of women with arteriosclerosis obliterans increased during the period covered by the study and this was also demonstrated for patients with arterial embolism.

The incidence of peripheral arterial insufficiency due to arteriosclerosis and diabetes mellitus in men increased over the years, and the increase could only to some extent be explained by changes in age distribution in the population.

Thrombangitis obliterans had been diagnosed less frequently in the later part of the period.

In the present study no preponderance for left or right could be proved. However, if the findings in other studies were taken into consideration it could be suspected that there is a preponderance for the left leg.

Bilateral involvement at the first admission was about 50 % more common in arteriosclerotics than in diabetics.

Most of the hospital admissions because of symptoms from the contralateral side took place within the first three years, and were more frequent in diabetics.

There was a decreased incidence of admission to hospital in late spring and summer with a peak value in the fall, and a true seasonal variation of these conditions could not be ruled out.

Women with arteriosclerosis obliterans had a shorter life expectancy than men with the same disease and died often shortly after the first admission. There was no difference in diabetics in this respe

sclerotic men had a longer survival than diabetic men but arteriosclerotic women had a shorter survival than diabetic women.

Patients with arterial embolism had a poor life expectancy.

Individuals with diabetes and vascular complications in the lower limbs had been older at the time of the diagnosis of diabetes than is usually found in a non-selected material of this disease. Vascular complications to juvenile diabetes were rare.

In 20 % of the cases with diabetes mellitus this diagnosis had not been known prior to the first admission for vascular complication. The average time interval between the diagnosis of diabetes and the first admission was about 10 years and significantly shorter for women.

Altogether 2,243 hospital admissions of 1,056 patients with peripheral arterial insufficiency were used for the calculation of the demand of this group of patients on the hospital facilities in the city.

The men stayed for each admission in hospital somewhat longer than women, i.e. if they were admitted to the somatic departments but not to the Chronic Somatic Department. Patients with diabetes needed longer hospitalization than arteriosclerotics.

When the patients were discharged from their first admission about half could return to their homes and the rest had to use other hospital or nursing facilities except for one fifth who died. Arteriosclerotic women could less frequently than other groups return to their homes and also died more frequently.

The annual hospital days consumed by these patients in the city increased from about 4,000 in 1949 to about 14,000 in 1965. For the four groups the increase was proportionate to the changes in incidence.

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REFERENCES

ALFFRAM, P.-A. (1964) An epidemiologic study of cervical and trochanteric fractures of the femur in an urban population. Analysis of 1,664 cases with special reference to etiologic factors. Acta orthop. scand. Suppl. 65.

ALFFRAM, P.-A. & BAUER, G. C. H. (1962) Epidemiology of fractures of the forearm. A biochemical investigation of bone strength. J. Bone Jt Surg. *44* A: 105.

ALFFRAM, P.-A. & HOLMQUIST, B. (1961) Amputationer på nedre extremiteten. Ett 10-års-material. Nord. Med. *65:* 356.

BADDELEY, R. M. & FULFORD, J. C. (1965) A trial of conservative amputations for lesions of the feet in diabetes mellitus. Brit. J. Surg. 52: 38—43.

BARTELS, C. C. & RULLO, F. R. (1958) Unsuspected diabetes mellitus in peripheral vascular disease. New Engl. J. Med. *259:* 633—635.

BELL, E. T. (1950) Incidence of gangrene of the extremities in non-diabetic and in diabetic persons. Arch. Path. *49:* 469—473.

— (1957) Atherosclerotic gangrene of the lower extremities in diabetic and non-diabetic persons. Amer. J. clin. Path. *28:* 27—36.

BERGE, T. (1967) The metastasis of carcinoma with special reference to the spleen. Acta path. microbiol. scand. Suppl. 188.

BIORCK, G. (1955) Rheumatic heart disease as a problem of preventive cardiology. J. chron. Dis. *1:* 591.

BLOCK, M. A. & WHITEHOUSE, F. W. (1963) Below-knee amputation in patients with diabetes mellitus. Arch. Surg. *87:* 682—689.

BLUMBERG, N. & ZISSERMAN, L. (1951) A twenty-year hospital survey of diabetic deaths. New Engl. J. Med. *244:* 833—837.

BLUMBERG, N. & ZISSERMAN, L. (1956) Diabetes in the older age group. Geriatrics *11:* 444—446.

BOYD, A. M. & BLOOR, K. (1959) The ischaemic leg. The surgery of arteriosclerosis of the lower extremities. Recent advances in surgery. J. A. Churchill Ltd. E. G. Taylor. 80—107.

BRADHAM, R. R. & SMOAK, R. D. (1965) Amputations of the lower extremity used for arteriosclerosis obliterans. Arch. Surg. *90:* 60—64.

BRYFOGLE, J. W. & BRADLEY, R. F. (1957) The vascular complications of diabetes mellitus. A clinical study. Diabetes *6:* 159—167.

BUGÁR-MÉSZÁROS, K. & BERECZKY, M. (1966) Beitrage zu dem Krankheitsbild der Arteriosclerosis Obliterans auf Grund von Beobachtungen an 1071 Kranken. Z. Kreisl.-Forsch *55:* 706—716.

BUSCHMANN, G., FRITZE, E. & MARSCH, A. (1958) Verlaufsbeobachtungen an 1500 Zuckerkranken. Dtsch. med. Wschr. *83:* 1284—1289.

BÜRGER, M. (1954) Angiopathia Diabetica Konservative Behandlung des Zuckerbrandes. Georg Thiemes Verlag, Stuttgart.

CAINE, D., KLEIN, R. & FREED, G. (1967) Amputation site and morbidity in relation to circulatory disease. Med. J. Aust. Aug. 5: 250—255.

CAMERON, H. C., LENNARD-JONES, J. E. & ROBINSON, M. P. (1964) Amputations in the diabetic. Outcome and survival. Lancet *2:* 605–607.

CARNEY, W. I. & GOLDOWSKY, S. J. (1957) Amputations in peripheral vascular disease. Amer. J. Surg. *93:* 795–797.

CLAUGUS, C. E., GRAHAM, G. C., BOWLING, E. C. & HAMILTON, J. E. (1958) Amputations of the lower extremity for arteriosclerosis. Arch. Surg. *76:* 992–996.

CONWAY, H. & MEIGHER, S. C. (1942) Infection and gangrene of the lower extremity in diabetes mellitus. N.Y. St. J. Med. *42:* 519–529.

DALE, W. A. & CAPPS, W. J. (1959) Major leg and thigh amputations; a ten year survey of results. Surgery *46:* 333–342.

DALE, W. A. & JACOBS, J. K. (1962) Lower extremity amputation· Results in Nashville 1956–60 Ann. Surg *155:* 1011–1022.

DE BAKEY, M E., CRAWFORD, E. S., GARRETT, H. E., COOLEY, D. A., MORRIS JR., G. C. & ABBOTT, J. P. (1964) Occlusive disease of the lower extremities in patients 16 to 37 years of age. Ann. Surg. *159:* 873–890.

DRY, T J. & HINES, E. A. (1941) The role of diabetes in the development of degenerative vascular disease with special reference to the incidence of retinitis and peripheral neuritis. Ann intern Med 14 1893–1902.

ELIASON, E L. & WRIGHT, V. W. M (1926) Diabetic and arteriosclerotic gangrene of the lower extremities Analysis of one hundred cases of amputation. Surg. Gynec. Obstet. *42:* 753–768

ENGSIG-KARUP, K. T. (1963) 1000 Underekstremitetsamputerede patienter. Bibl Laeger *155* 1–21.

ENOS, W F, HOLMES, R. H. & BEYER, J (1953) Coronary disease among U.S. soldiers killed in action in Korea J. Amer. med. Ass *152·* 1090–1093.

FAXON, H. H. (1939) Major amputations for advanced peripheral arterial obliterative disease. J Amer. med Ass. *113.* 1199–1203

FITZGERALD, M. G., MALINS, J M., O'SULLIVAN, D. J. & WALL, MARY (1961) The effect of sex and parity on the incidence of diabetes mellitus. Quart. J. Med. *30:* 57–70.

GAMBLE, D R & TAYLOR, K W. (1969) Seasonal incidence of diabetes mellitus. Brit. med J. 3. 631–633

GENSLER, S W, HAIMOVICI, H., HOFFERT, P, STEINMANN, C. & BENEVENTANO, T. C. (1965) Study of vascular lesions in diabetic, non-diabetic patients. Arch. Surg. *91:* 617–622

GOLDNER, M G. (1960) The fate of the second leg in the diabetic amputee. Diabetes *9* 100–103

GOLDNER, M G, ASLAN, U. & ULLBOR, O N. (1959) Das Schicksal des zweiten Beines bei amputierten Diabetikern. Medizinische *1* 29–32

HAIMOVICI, H (1950) Peripheral arterial embolism A study of 330 unselected cases of embolism of the extremities Angiology *1:* 20–45

– (1967) Patterns of arteriosclerotic lesions of the lower extremity. Arch. Surg. 95: 918–933

HALL, P. (1961) On the prognosis and natural history of acute rheumatic fever and rheumatic heart disease Acta med. scand. Suppl. 362.

HANSSON, J (1964) The leg amputee. A clinical follow-up study. Acta orthop. scand. Suppl. 69.

HASSE, H M see RATSCHOW, M. (1959) Angiologie.

HEINE, H. & SCHMIDT, H. (1966) Resultate konservativer Therapie bei arteriellen Durchblutungsstörungen mit Gangrän. Z ges. inn Med *21:* Suppl. 271–273.

HENSCHEN, F. (1953) Geographic and historical pathology of arteriosclerosis. J. Geront. *8: 1:* 1—5.

HINES, JR. E. A. & BARKER, N. W. (1940) Arteriosclerosis obliterans. A clinical and pathological study. Amer. J. med. Sci. *200:* 717—730.

JOHN, H. J. (1938) Surgery and diabetes. Ann. Surg. *108:* 1052—1075.

— (1950) Statistical study of 6000 cases of diabetes. Ann. intern. Med. *33:* 925—940.

JOSLIN, E. P. (1934) The menace of diabetic gangrene. New Engl. J. Med. *211:* 16—20.

JUERGENS, L., BARKER, N. W. & HINES, E. A. (1960) Arteriosclerosis obliterans: Review of 520 cases with special reference to pathogenic and prognostic factors. Circulation *21:* 188—195.

JUNG, H. D., SCHLIACK, V. & SCHNEIDER, W. (1968) Zur Signifikans der Häufigkeitsunderschiede der Diabetesmorbiditat in Stadt- und Landbezirken. Dtsch. Gesundh.-W, *23:* 1854—1857.

KAYE, J., BERMAN, V., BERK, M. E., ROSENBERG, B., EPSTEIN, E. & SNEIDER, P. (1963) Peripheral vascular disease in Johannesburg. An analysis of 269 peripheral arteriograms *performed at the Johannesburg General Hospital.* S. Afr. med. J. *37:* 345—347.

KRAMER, D. W. (1932) Diabetic gangrene; Incidence and pathogenesis: An Analysis of 58 cases among 1008 diabetics. Amer. J. med. Sci. *183:* 503—514.

KRAMER, D. W. & PERILSTEIN, P. K. (1955) Peripheral vascular disorders in diabetes mellitus. A survey of 3000 cases. Angiology *6:* 408—416.

KRAMER, D. W. & PERILSTEIN, P. K. (1958) Peripheral vascular complications in diabetes mellitus. A survey of 3,600 cases. Diabetes *7:* 384—387.

KRAUTWALD, A. & VOLPEL, W. (1959) Lokalisation arterieller Obliterationen bei 1166 gefasskranken unteren Extremitäten als Grundlage für die Beurteilung terapeutischer Massnahmen. Z. Kreisl.-Forsch. *48:* 575—580.

LINDAHL, F. & BOLUND, S. (1969) Amputationer på underekstremiteterne. Ugeskr. Laeg. *131:* 365—368.

LINDHOLM, R. (1964) Features of amputation surgery among civilians during the period 1930—1960. Acta orthop. scand. *35:* 74—89.

MALINS, J. M. et al. (Diabetes Survey Working Party) (1963) Glucose tolerance and glycosuria in the general population. Brit. med. J. Sept. 14: 655—659.

MAZET JR., R. (1967) The geriatric amputee. Artif. Limbs *11:* 33—41.

MAZET JR., R., SCHILLER, F. J., DUNN, O. J. & NEUFELD, A. J. (1963) The influence of prosthesis wearing on the health of the geriatric patient, Project 431, supported by the Office of Vocational Rehabilitation, March 1963. Quoted by Warren & Kihn. (1968).

MCKITTRICK, L. S. (1940) Diabetic gangrene: Review of 972 cases of gangrene associated with diabetes mellitus treated at New England Deaconess Hosp. Arch. Surg. *40:* 352—363.

MCLAUGHLIN JR., C. W. (1943) Problems in the surgical management of diabetic gangrene. Surgery *13:* 423—433.

MCLAUGHLIN JR., C. W. & HEIDER, C. F. (1955) Infection and gangrene in the extremities of aging diabetics. Geriatrics *10:* 571—574.

MCLAUGHLIN JR., C. W. & HEIDER, C. F. (1955) The continuing problem of infection and gangrene in the diabetic extremity. Amer. J. Surg. *89*· 964—967.

MCLAUGHLIN JR., C. W. & WIEDMAN, J. G. (1950) Infection and gangrene in the diabetic *extremity. A critical* review of surgical management over a seventeen-year period. Neb. St. med. J. *35: 10:* 316—319.

MELLINGHOFF, K. (1955) Die Gefässpatschäden bei Zuckerkrankheit und ihre Problematik. Med Klin. *50:* 193—197.

MITTY, W. F. & ALMEDA, I. C. (1967) Major amputations of extremities. N.Y. St. J. Med. *67*: 3086—3089.

MORRISON, H. (1916) Statistical study of mortality from diabetes mellitus in Boston from 1895—1913. Boston med. surg. J. *175*: 54—57.

MOZES, M., CAHANSKY, G., DOITSCH, V. & ADAR, R. (1970) The association of atherosclerosis and Buerger's disease: A clinical and radiological study. J. cardiovasc. Surg. *11*: *1*: 52—59.

NIELSEN, J. (1969) Thrombangitis obliterans Buerger. En prognosstudie. Ugeskr. Laeg. *131*: 1740—1751.

OAKLEY, W., CATTERHALL, R. C. F. & MARTIN, M. M. (1956) Aetiology and management of lesions of feet in diabetes. Brit. med. J. *1*: 953—957.

OAKLEY, W. & COHEN, S. M. (1954—1955) Diabetic gangrene. Trans. med. Soc., London *71*: 90—107.

OTTEMAN, M. G. & STAHLGREN, L. R. H. (1965) Evaluation of factors which influence mortality and morbidity following major lower extremity amputations for arteriosclerosis. Surg. Gynec. Obstet. *120*. 1217—1220.

PAVY, F. W. (1885) Introductory address to the discussion on the clinical aspect of glycosuria. Lancet *2*: 1033—1035.

PERLOW, S. (1962) Amputation for gangrene because of occlusive arterial disease. Amer. J. Surg. *103*: 569—574.

PINCUS, G., JOSLIN, E. P., WHITE, P. (1934) The age-incidence relations in diabetes mellitus. Amer. J. med. Sci. *188*. 116—121.

PREUSS, E.-G., HAUSLER, M. & SEIGE, K. (1969) Obliterierende arterielle Systemerkrankungen bei Frauen. Dtsch. Gesundh.-W. *24*: 577—584.

PYKE, D. A. (1956) Parity and the incidence of diabetes. Lancet *1*: 818—820.

RABINOWITCH, I. M., RITCHIE, W. L., & MCKEE, S. H. (1934) A statistical evaluation of different methods for the detection of arteriosclerosis in diabetes mellitus. Ann. intern. Med. *7*: 1478—1490.

RABKIN, M. T. & FIELD, R. A. (1962) The impact of diabetes mellitus on the responsibilities of a general hospital. A retrospective statistical study of admissions of diabetics to the Mass. Gen. Hosp. in the year 1957. J. chron. Dis. *15*: 91—103.

RATSCHOW, M. (1959) Angiologie. Pathologie, Klinik und Therapie der peripheren Durchblutungsstorungen. Georg Thieme Verlag, Stuttgart.

REMEIN, Q. R. (1959) A current estimate of the prevalence of diabetes mellitus in the United States. Ann. N.Y. Acad. Sci. *82*: 229—235.

ROOT, H. F. et al. (1955) Surgical lesions of diabetic feet. New Engl. J. Med. *253*: 685—688.

ROSENBERG, N., ADIARTE, E., BUDJOSO, L. J. & BACKWINKEL, K. D. (1970) Mortality factors in major limb amputations for vascular disease: A study of 176 procedures. Surgery *67* No. 3. 437—441.

RUSSEK, A. S. Quoted by WILDER et al. (1966)

SCHADT, D. C., HINES, E. A., JUERGENS, J. L. & BARKER, N. W. (1961) Chronic atherosclerotic occlusion of the femoral artery. J. Amer. med. Ass. *175*: 937—940.

SCHEIBE, O. & GALLENKAMP, H. (1968) Die Arteriosklerose des Diabetikers als spezifische Folgekrankheit des Diabetes mellitus. Med. Welt *9*. 415—421.

SCHLIACK, V. (1959) Diabetes-Reihenuntersuchungen. Dtsch. med. Wschr. *84*: 1446—1448.

SCHNEEWEISS, J. & GASSMANN, W. (1955) Gangrän bei Diabetes Mellitus. Med. Klin. *50*: 853.

SEMPLE, R. (1953) Diabetes and peripheral arterial disease; a clinical study. Lancet *1*, *22*: 1064—1068.

HENSCHEN, F. (1953) Geographic and historical pathology of arteriosclerosis. J. Geront. *8: 1:* 1—5.

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MELLINGHOFF, K. (1955) Die Gefasspatschäden bei Zuckerkrankheit *und ihre Problematik.* Med Klin. *50:* 193—197.

MITTY, W. F. & ALMEDA, I. C. (1967) Major amputations of extremities. N.Y. St. J. Med. *67*: 3086—3089.

MORRISON, H. (1916) Statistical study of mortality from diabetes mellitus in Boston from 1895—1913 Boston med. surg. J. *175*: 54—57.

MOZES, M., CAHANSKY, G., DOITSCH, V. & ADAR, R. (1970) The association of atherosclerosis and Buerger's disease: A clinical and radiological study. J. cardiovasc. Surg. *11*: *1*: 52—59.

NIELSEN, J. (1969) Thrombangitis obliterans Buerger. En prognosstudie. Ugeskr. Laeg. 131: 1740—1751

OAKLEY, W., CATTERALL, R. C. F. & MARTIN, M. M. (1956) Aetiology and management of lesions of feet in diabetes. Brit. med. J. *1*: 953—957.

OAKLEY, W. & COHEN, S. M. (1954—1955) Diabetic gangrene. Trans. med. Soc., London *71*: 90—107.

OTTEMAN, M. G. & STAHLGREN, L. H. H. (1965) Evaluation of factors which influence mortality and morbidity following major lower extremity amputations for arteriosclerosis Surg. Gynec Obstet. *120*. 1217—1220.

PAVY, F. W. (1885) Introductory address to the discussion on the clinical aspect of glycosuria Lancet *2*: 1033—1035.

PERLOW, S. (1962) Amputation for gangrene because of occlusive arterial disease. Amer. J. Surg *103* 569—574.

PINCUS, G., JOSLIN, E. P., WHITE, P. (1934) The age-incidence relations in diabetes mellitus Amer. J. med Sci. *188*: 116—121.

PREUSS, E.-G., HÄUSLER, M. & SEIGE, K. (1969) Obliterierende arterielle Systemerkrankungen bei Frauen. Dtsch. Gesundh.-W. 24: 577—584.

PYKE, D. A. (1956) Parity and the incidence of diabetes Lancet *1*: 818—820.

RABINOWITCH, I. M., RITCHIE, W. L., & MCKEE, S. H. (1934) A statistical evaluation of different methods for the detection of arteriosclerosis in diabetes mellitus. Ann. intern Med *7*: 1478—1490

RASKIN, M. T. & FIELD, R. A. (1962) The impact of diabetes mellitus on the responsibilities of a general hospital. A retrospective statistical study of admissions of diabetics to the Mass Gen Hosp in the year 1957. J chron. Dis. *15*. 91—103

RATSCHOW, M. (1959) Angiologie Pathologie, Klinik und Therapie der peripheren Durchblutungsstörungen. Georg Thieme Verlag, Stuttgart.

REMEIN, Q. R. (1959) A current estimate of the prevalence of diabetes mellitus in the United States Ann. N. Y. Acad. Sci. *82*: 229—235.

ROOT, H. F. et al (1955) Surgical lesions of diabetic feet New Engl. J. Med. *253*: 685—688.

ROSENBERG, N., ADIARTE, E., BUDJOSO, L. J. & BACKWINKEL, K. D. (1970) Mortality factors in major limb amputations for vascular disease: A study of 176 procedures. Surgery 67 No. 3 437—441.

RUSSEK, A. S. Quoted by WILDER et al. (1966)

SCHADT, D. C., HINES, E. A., JUERGENS, J. L. & BARKER, N. W. (1961) Chronic atherosclerotic occlusion of the femoral artery. J. Amer. med. Ass. *175*: 937—940.

SCHEIBE, O. & GALLENKAMP, H. (1968) Die Arteriosklerose des Diabetikers als spezifische Folgekrankheit des Diabetes mellitus. Med. Welt *9*: 415—421.

SCHLIACK, V. (1959) Diabetes-Reihenuntersuchungen. Dtsch. med. Wschr. *81*: 1446—1448.

SCHNEEWEISS, J. & GASSMANN, W. (1955) Gangrän bei Diabetes Mellitus. Med. Klin. *50* 853

SEMPLE, R. (1953) Diabetes and peripheral arterial disease; a clinical study. Lancet *1*. *22*: 1064—1068

SHUMACKER JR., H. B. & MOORE, T. C. (1951) Leg and thigh amputations in obliterative arterial disease. Arch. Surg. *63:* 458—465.

SIEVERS, J. (1963) Myocardial infarction. Clinical features and outcome in three thousand thirty-six cases. Acta med. Scand. Suppl. 406.

SILBERT, S. (1948) Mid-leg amputations for gangrene in the diabetic. Ann. Surg. *127:* 503—512.

— (1952) Amputation of the lower extremity in diabetes mellitus. Diabetes *1:* 297—299.

SILBERT, S. & HAIMOVICI, H. (1950) Results of mid-leg amputations for gangrene in diabetics. J. Amer. med. Ass. *144:* 454—458.

SILBERT, S. & Zazeela, H. (1958) Prognosis in arteriosclerotic peripheral vascular disease. J. Amer. med. Ass. *16:* 1816—1821.

SILWER, H. (1958) Incidence of diabetes mellitus in a Swedish county survey of diabetics in the County of Kristianstad. Acta med. Scand. Suppl. 335.

SINGER, A. & ROB, C. (1960) The fate of the claudicator. Brit. med. J. *2:* 633—636.

SKVERSKY, N. & Zislis, J. M. (1970) Peripheral-vascular disorders and the aged amputee. Geriatrics *25:* 142—149.

SMITH, B. C. (1956) A twenty-year follow-up in fifty below-knee amputations for gangrene in diabetics. Surg. Gynec. Obstet. *103:* 625—630.

SOLTH, K., KOHL, R., SCHLETTER, G. & WERTHEMAN, A. (1957) Zur Statistik der Arteriosklerose. Verh. Path. Ges. Bad. Nauheim *41:* 64—77.

SPAULDING, W. B. (1956) The prognosis of patients with intermittent claudication. Canad. med. Ass. J. *75:* 105—111.

SPIEGELMAN, M. & MARKS, H. H. (1946) Age and sex variations in the prevalence and onset of diabetes mellitus. Amer. J. publ. Hlth *36:* 26—33.

STERNBY, N. H. (1968) Atherosclerosis in a defined population. An autopsy survey in Malmo, Sweden. Acta path. microbiol. scand. Suppl. 194.

THOMPSON, J. E., SIGLER, L., RAUT, P. S., AUSTIN, D. J. & PATMAN, R. D. (1970) Arterial embolectomy: a 20 year experience with 163 cases. Surgery *67: 1:* 212—220.

THURSBY, P. F. & DUNN, R. M. (1970) Amputations of the lower limb in a repatriation hospital. Med. J. Aust. *1:* 161—166.

WARREN, R. & KIHN, R. B. (1968) A survey of lower extremity amputations for ischaemia. Surgery *63: 1:* 107—120.

WESSLER, S. & SHEPS, G. (1958) Studies in peripheral arterial occlusive disease III. Acute arterial occlusion. Circulation *17:* 512—525.

WESSLER, S., MING, S. C., GUREWICH, V. & FREIMAN, D. G. (1960) A critical evaluation of thrombangitis obliterans. The case against Buerger's disease New Engl. J. Med. *262: 23:* 1149—1160.

WHITE, P. (1956) Natural course and prognosis of juvenile diabetes. Diabetes *5:* 445—450.

WHITEHOUSE, F. W., JURGENSEN, C. & BLOCK, M. A. (1968) The later life of the diabetic amputee. Another look at fate of the second leg. Diabetes *17:* 520—521.

WIDMER, L. K., GREENSHER, A. & KANNEL, W. B. (1964) Occlusion of peripheral arteries. A study of 6400 working subjects. Circulation *30:* 836—842.

WILDER, J. R., ASCOLI, N., STURCHIO, E. A. & POPOWITZ, L. (1966) Management of diabetes with vascular disease of lower extremities. N.Y. St. J. Med. June 15· 1651—1658.

VISKUM, K. (1969) The prognosis of conservatively treated diabetic gangrene. Acta med. scand. *185:* 319—322.

WRIGHT, J. S. (1960) Amputations for gangrene in diabetics. Med. J. Aust. Oct. *8:* 574—575.

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FREDERICK G. LIPPERT III

A LONG LEG BRACE FOR COMPREHENSIVE FORCE MEASUREMENT

Design and Experimental Studies

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ACTA ORTHOPAEDICA SCANDINAVICA
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From the Department of Orthopaedic Surgery, Karolinska Hospital, Stockholm, Sweden
Head CARL HIRSCH

A LONG LEG BRACE FOR COMPREHENSIVE FORCE MEASUREMENT

Design and Experimental Studies

By
FREDERICK G. LIPPERT III

MUNKSGAARD
COPENHAGEN 1971

This work is dedicated to my wife, Nona and our three children: Nina, Felicia and Todd.

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PREFACE

During my residency training 1966—1970 at the University of Vermont, Burlington, Vermont, the extent to which engineering principles could be applied to orthopaedic surgery became increasingly evident. This relationship was further emphasized by contacts with Professors Victor Frankel and Albert Burstein. Because of my engineering-oriented background I felt a strong desire to become more acquainted with this field by undertaking a biomechanical research study.

Following discussions with Professor and Chairman Frank Hoaglund it was recommended that I seek a biomechanical research fellowship with Professor Carl Hirsch, Chairman of the Department of Orthopaedics, Karolinska Hospital, Stockholm, Sweden Due to his renowned reputation for basic research in this field, it was anticipated that I would obtain the best indoctrination possible in the experimental approach and measuring techniques necessary for biomechanical studies.

Shortly afterwards the author was challenged one morning on rounds by visiting Professor Arthur Hodgson from Hong Kong concerning the efficacy of weight-bearing braces. A preliminary search of the literature revealed an astonishing lack of quantitative data to answer this question. It was then that the idea to design a method for quantitating forces between the leg and brace occured. Further discussions with Dr Richard McLay of the Mechanical Engineering Department of the University of Vermont confirmed the feasibility of such a project.

Later the same year Professor Hirsch visited the University of Vermont and the idea was presented to him. He immediately recognized the possibilities and extended an invitation for me to come to Sweden and pursue the work.

Largely through the interest and support of Drs Frank Hoaglund, John Frymoyer, Phil Davis and other members of the Department of Orthopaedic Surgery at the University of Vermont, financial arrangements were made to help defray my fellowship expences.

The major part of this work was done in collaboration with the Instrumentation Department of The Aeronautical Research Institute of Sweden. Their expertise in the use of instrumentation techniques was well utilized in solving the measuring problems

INTRODUCTION

Many affections of the lower extremity are treated and protected in orthotic appliances. In the United States the ratio of prosthetic to orthotic needs is 10/1 (Rehabilitation Engineering 1971). The field of orthotics has not kept abreast with the advances in prosthetics and technology. It has only been within the past 10 years that significant results from orthotic research efforts have begun to emerge.

Despite the number of orthotic devices prescribed, the manner of formulating an orthotic prescription and selecting the appropriate device is ill-defined (McCollough, 1970). To merely state the need for an appliance is insufficient. The physician involved must be able to establish the biomechanical aspects of his patient's disability and then use them to translate his medical objectives into specific orthotic objectives. Finally he is faced with the problem of filling the prescription from a bewildering array of manufactured appliances which are poorly classified as to their specifications and indications (Henderson & Lamoreaus, 1969, Murdoch, 1970). It is no wonder that controversy exists over the functions a given brace can perform and that different prescriptions are written for the same problem.

Appliances are assumed to perform functions for which they are unqualified while their detrimental effects remain either unknown or unheeded. The traditional ambulatory treatment of Legg-Perthe's disease in an ischial weight-bearing brace presupposes that loads on the affected femoral head will be diminished (Glimcher et al., 1970). In fact, the additional forces needed to accelerate or decelerate the braced limb by muscles spanning the diseased joint exceed body weight (Frankel and Burstein, 1970). The assumption that femoral fractures treated in weight-bearing cast braces can be effectively unloaded has been seriously challenged by Mooney et al. (1970). That the fractures heal may in fact be more related to the amount of loading which does occur because of the brace's ineffectiveness.

Braces which span joints limit their normal intersegmental motions in the transverse, frontal and sagittal planes (Viel, 1968). These motions act to conserve energy requirements by facilitating the interchange of potential and kinetic energy and reducing center of gravity excursions (Inman, 1968). A

of this test brace. I am most grateful to Department Head Knut Fristedt for his help in evolving the final brace design after many discussions and interchange of ideas. Through him I have learned valuable concepts about various instrumentation techniques. Electronics engineer Lennart Magnusson maintained the recording equipment in an operational status and offered many practical suggestions during our close association in the gait laboratory.

Ragnar Ranveg, Head of The Prosthetics-Orthotics Workshop, Department of Orthopaedic Surgery, Karolinska Hospital, and his staff did a fine job in constructing the plaster positive of my leg, the plastic laminated thigh shells and the shoe components.

My appreciation is extended to the visiting biomechanical engineers, Leon Kazarian, Albert Schultz and also Bo Klasson, Head, Prosthetic Research Laboratory Norrbacka Institute, for their stimulating criticisms of the engineering aspects of this study; and to Drs John Kenwright and Manhar Patel for their clinical discussions.

I also wish to thank Lennart Jansson for the photography, Ingrid Ledström for help with administrative details, Vivian Kenwright for help with data reduction and Kerstin Sanfridson for typing assistance.

This project was supported by:

1 The State Medical Research Council (Grant: Hirsch, B71-17x-565-07 and B72-17x-565-08).
2 Karolinska Institute, Stockholm.
3 Ulla and Gustaf af Ugglas' Foundation.
4 King Gustaf V's 80th Anniversary Foundation.
5 The Swedish National Association Against Rheumatism.

It has been my privilege as a citizen of the United States to publish this work as a thesis in Sweden, which was made possible by academic grants.

Frederick G. Lippert III
Stockholm in November 1971

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locked knee increases the total energy cost by up to 25% (Viel, 1968; Inman, 1968). Malalignment of brace joints produces excessive wear on the appliance and potentially detrimental effects on the patient (Lechlitner, 1966; von Werssowetz, 1962).

Research *in the field of lower extremity* orthotics today is hampered by the lack of quantitative clinical data, no standardized means of acquiring this clinical data and the inability to correlate clinical findings with a particular brace. Consequently long range response predictions to orthoses *can only be speculated.* (Lehmann et al., 1970.)

Brace research and development is mostly based on past experience and clinical observations which results in overdesign; excessive safety margins, increase in weight and bulk (Lehneis, 1969). In order to develop an optimal brace configuration clinical evaluation must be supplemented with biomechanical analysis. This combined approach provides a broader insight into the dynamic behavioral characteristics of the leg-brace system, and enables responses to be predicted for which no directly applicable empirical data is available. Design and modification can then be accomplished with more confidence that the desired clinical result will be obtained.

Approach to the problem

Biomechanical analysis of lower extremity braces can be approached *in* several ways One is to instrument and study standard appliances. This method is easier but limited in the information obtained because of the susceptibility of such flexible systems to large cross-sensitivity errors. Another approach and the one taken by the author is to design a test brace, simulate selected prescriptions and study force-time histories. This comprehensive approach helps to define broader force envelopes, yield more realistic response predictions, provide a greater understanding of the biomechanical nature of the interacting systems, facilitate the correlation of physiological and psychological responses with mechanical input and enable a more scientific approach to brace design.

Purpose and objectives

The purpose of this project was to study the interactions between the brace and leg by the analysis of force-time histories recorded from selected ischial weight-bearing brace combinations.

The project was divided into two basic parts:

I. The design of a test brace, compatible instrumentation and reliable *data acquisition and analysis* techniques

II The application of the test equipment and methods to a general investigation on selected ischial weight-bearing brace combinations

Specific information was sought about the following:

1. The magnitude of forces and moments to which specific brace structures and the leg are subjected.

2. The magnitude and distribution of loading which occurs on the brace with different thigh shell configurations.

3. The degree of weight relief (or skeletal unloading) experienced by the leg with different brace combinations as a function of:

   a) the anterior wall in the seat shell and maintainance of ischial seat contact

   b) patten bottom vs. shoe attachments

   c) fixed and hinged ankle joints

4. The significance of the joint hinge location on calf band force patterns
   a) heel hinge
   b) ankle hinge

5. The effect of foot alignment on the calf band force patterns
   a) free ankle; internal, neutral, external rotation
   b) fixed ankle; dorsiflexion, neutral, plantarflexion

6. Rotational and angulatory stability imparted to the extremity within the thigh shell.

7. Brace loading caused by muscle forces

8. Alteration of the gait pattern expressed in terms of the contact duration of each foot position and the timing of force maximums.

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knee are currently under evaluation (Staros, 1971)

Several authors have reported encouraging results using cast and conventional braces for the early ambulatory treatment of fractures (Mooney and Harvey, 1970) and delayed union (Werner, 1969). Because of the array of brace components available from different manufacturers with no standard classification system, Staros (1971) has suggested a system of component classification based on whether the device prevents, limits, resists or permits joint motion

McCollough et al (1970) has described a systematic approach to orthotic prescription which should help to standardize terminology and facilitate a more accurate asscessment of the disability

By contrast to these numerous, diversely oriented and qualitative approches to orthotic research, quantitative studies devoted to force measurements are limited (Prosthetics and Orthotics, 1967).

Glimcher (1950) reported stress analysis studies conducted on an instrumented long-leg brace Strain gages mounted on the medial upright ard horizontal bands were used to study the effects of strap tightening and ambulation However, applied forces could not be directly measured because of cross-sensitivity difficulties

Desai and Henderson (1961) designed a short-leg brace with a double axis ankle which permited both ankle and subtalar motion.

Staros and Peizer (1965) evaluated the unweighting effectivness of the Veterans Administration Prosthetics Center Below-Knee, Weight-Bearing Brace by simultaneously measuring an instrumented stirrup assembly and force plate output signals Maximal unweighting occured at heel strike and was different on the right and left sides

Hodge (1967) statically loaded an instrumented aluminum ischial weight-bearing brace which was mounted in a jig. Loads up to 250 lbs were applied and stresses from lateral deflections at the ankle and knee levels were computed. He considered this type of loading more conducive to structural failure than axial loads. From the stresses calculated aluminum was considered a suitable material for weight-bearing braces.

Magora et al. (1968) and Robin et al (1968) instrumented lower leg drop-foot braces and computed stresses from recorded strain output signals using different gait patterrs on a normal subject. Stress patterns indicated that posterior spring-type braces were more susceptible to fatigue failure

A series of biomechanical studies have been conducted at the University of Washington, Seattle in conjunction with the Departments of Mechanical Engineering and Physical Medicine and Rehabilitation (Kirkpatrick et al, 1969, Lehmann et al., 1969 and 1970).

By using sophisticated data acquistion and analysis techniques, instrumented brace ard floor reaction output signals are synchronized, digitized, interfaced with a computer and subsequently printed out in the form of fully integrated force-time histories

SURVEY OF THE LITERATURE

Organized research efforts in the field of lower extremity orthotics did not appear until 1956 when the experience gained in prosthetics from working with veteran amputees was found also applicable to the allied field of orthotics (Wilson, 1963).

The main stream of lower extremity orthotic research has been oriented toward qualitative improvements in design, wider application to more acute problems such as fracture treatment and administrative efforts to systematize orthotic prescription, component classification and prefabrication (Staros, 1971). Several recent and detailed reviews cover the current trends in orthotics (Lehneis, 1969; Lehmann, et al., 1970; Report of Seventh Workshop Panel, 1970). A representative survey is presented to distinguish this type of research from the quantitatively oriented nature of biomechanical force-measurement studies (Braces, Splints and Assistive Devices, 1969; Cochran, 1971).

Anderson and Bray (1964) and Strohm et al. (1966) reported a functional long-leg brace designed to permit ambulation without knee locks. Grynbaum et al. (1969) reported an adjustable ischial weight-bearing brace which featured an inflatable anterior wall lining to maintain a snug fit and reduce the number of brace sizes required in stock. Russek (1958) attached a wood quadrilateral socket to the proximal end of an ischial weight-bearing brace to provide better support. Recognizing that hip joint forces developed during ambulation often exceed body weight, and that this was partly due to the abductor muscle group activity, Glimcher et al. (1970), are developing an ischial weight-bearing brace used for the treatment of Legg-Perthe's disease which requires the patient to balance on the end of a single medial upright without any leg fixation thus keeping the abductor muscle group inactive.

Plastic materials which are lighter than steel or aluminum and cosmetically more appealing are being utilized in below knee orthoses such as the spiral helix drop-foot brace (Fifth Workshop Panel on Lower Extremity Orthotics) and corrugated polypropylene versions of different below and above knee orthoses (Engen, 1970) Attempts have been made to more closely follow anatomic joint motion Polycentric joint designs which simulate the multiplanar motion of the

knee are currently under evaluation (Staros, 1971).

Several authors have reported encouraging results using cast and conventional braces for the early ambulatory treatment of fractures (Mooney and Harvey, 1970) and delayed union (Werner, 1969). Because of the array of brace components available from different manufacturers with no standard classification system, Staros (1971) has suggested a system of component classification based on whether the device prevents, limits, resists or permits joint motion

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By using sophisticated data acquistion and analysis techniques, instrumented brace and floor reaction output signals are synchronized, digitized, interfaced with a computer and subsequently printed out in the form of fully integrated force-time histories

by a Calcomp plotter. This measuring technique has facilitated a series of force-measurement studies on the performance characteristics of standard braces.

From these studies the unloading effectiveness of ischial weight-bearing braces has been seriously challenged. Optimal effectiveness was found with a quadrilateral thigh shell, fixed ankle, metal sole plate extending to the metatarsal heads, rocker bottom attachment and skilfull loading by the wearer.

The effect of different instrumented below knee braces on knee stability was evaluated by measuring calf band forces exerted against the leg. The forces cause knee flexion and extension moments which substantiates quantitatively what has been known clinically about the effect of heel and toe lever arms.

Mooney and Harvey (1970 investigated the weight-bearing properties of total contact cast braces used for recent femoral and tibial plateau fratures. Static comparisons between forces at the knee and floor showed unloading to be inversely proportional to body weight. Dynamic studies were not conducted.

INSTRUMENTATION AND TEST PROCEDURE

The Design of a Measuring System

In order to design and construct a functional test brace, compatible instrumentation and related equipment the Instrumentation Dept of the Aeronautical Research Institute of Sweden and the Prosthetic-Orthotic Workshop of the Dept of Orthopedic surgery, Karolinska Hospital, Stockholm, were consulted Throughout the project is was necessary to maintain a close working relationship with the two disciplines.

The primary objective was to measure forces during ambulation exerted on the leg-brace interfaces. These forces arise from a combination of muscular activity, body weight, inertial and ground reactions. The method used in principle was to attach representative brace interfaces to the leg and study the resulting dynamic interactions

In practice this was accomplished by fastening the interfaces to a measuring system which was mounted on a frame of sufficient stiffness to prevent mutual interactions between the interface segments A typical ischial weight-bearing brace is attached to the leg by essentially four segments which have the following functions:

1. ischial seat platform, lateral and anterior walls: provide weight bearing and rotational control
2. corset: provides alignment and partial weight bearing
3. calf band: provides alignment but no weight bearing
4. foot assembly: provides alignment and foundation for the brace structure.

A study of individual forces acting on each contacting segment will yield a clearer picture of the overall performance at different levels.

The interactions between the leg and brace are represented by a combination of moments and forces. In order to have a statically determinate system is was necessary to convert the forces and moments into three orthogonal force components at three different points on the two upper brace rings corresponding to the seat and corset areas. This was achieved by using universal couplings between the leg-brace interface assemblies and the measuring system.

In the lower segment the calf transducers were aligned so as to record only the transverse plane components X and Z; and the ankle transducers

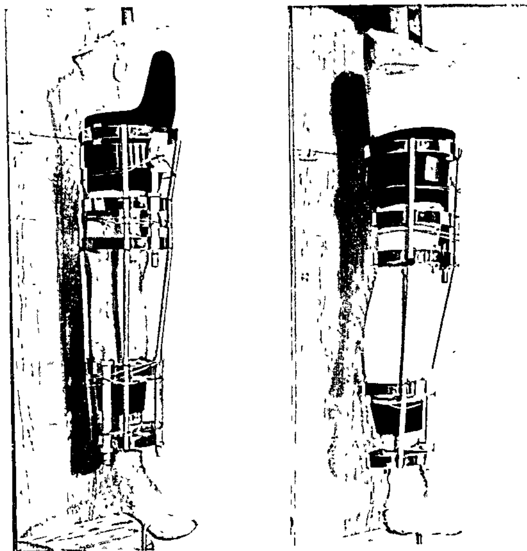


Figure 1 Positive plaster model and brace mockup under construction

only the brace long axis component Y. Fig. 17 c shows the orthogonal force component system.

The force components applied to each transducer were predicted from estimates based on a known body weight of 61kp acting vertically downward on a brace system undergoing maximal inclinations from the vertical of approximately 14 degrees. At the slightly slower than normal walking speeds expected inertial forces were considered neglible.

Vertical floor reactions were correlated with the brace forces by utilizing the 5 meter electronic walkway (Rydell, 1966) in the gait laboratory of the Department of Orthopaedics, Karolinska Hospital. Since preliminary measurements, taken during ambulation, showed the maximal angle of the brace's long axis to be in the

sagittal plane, 14 degrees, and in the frontal plane, 5 degrees, conversion of floor reaction forces to the brace axis as described by Lehmann et al. (1970) was not considered necessary. The cosine of small angles approaches 1, and the difference is too small to justify more complicated photographic methods of angle measurement.

Brace Construction

The design objective was to provide a structure of sufficient stiffness to prevent interactions from occuring between the leg-brace interface assemblies. Following the preliminary discussions, a positive plaster of paris model of the author's left leg was prepared (Fig. 1). This served as a basis on which to construct a wood mockup of the initial brace assembly, to locate the longitudinal structures and cross sections, to limit column length and determine the locations of transducer placement

Early in the study it was concluded that the basic assembly must be divided into an upper and lower segment in order to facilitate entry and egress

Construction material was:

Aluminum SM 6508 (weldable),
Svensk norm 515 4212-6
$E = 7000$ kp mm²
$\sigma_{s} = 25$ kp/mm²

Each segment is constructed of circular ring sections and four longitudinal 10 mm solid tubular uprights (Fig 2)

The individual segments were jigged, argon welded and mechanically fastened to each other. In the completed assembly applied loads were transferred to the longitudinal members which were stabilized by the circular cross sections Cutouts were kept to a minimum to maximize the brace's stiffness and reduce the bending and torsional deflections during loading. The assembled configuration is in the form of a truss made of Duraluminum which provides a high degree of struc-

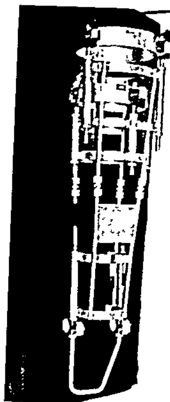


Figure 2. Complete brace without wiring. Couplings between the the upper and lower segments are seen above the stiffner plates.

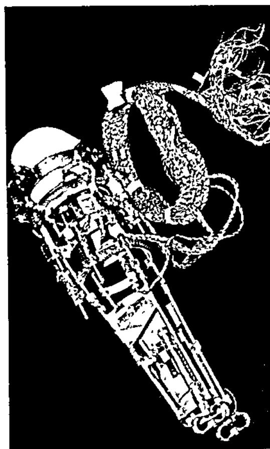


Figure 3. Fully assembled brace with shells, calfband and cabling

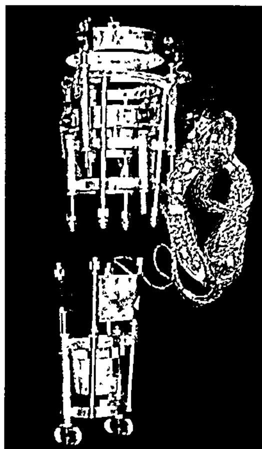


Figure 4 Upper and lower segments uncoupled.

tural rigidity with minimum weight (Fig. 3 & 4).

Onto the basic structural assembly were welded eight uniaxial and parallel keyed telescoping fixtures which provided a means of securely mounting, adjusting and locking the seat, corset and foot-ankle assemblies. The strain gage transducer bodies were mechanically fitted onto the telescoping fixtures and served as a mount to interface the sensing elements with the seat and corset and foot-ankle assemblies

Transducers

The basic principle underlying the design of the transducers was that moments applied to a beam on which sensing elements are mounted produce greater strains per given force than direct compressive or tensile forces.

Six transducer bodies support the thigh segments and convert via universal couplings the forces and moments transmitted from the leg to the brace into six different reaction forces Each transducer body has the ability to resolve its own force into three ortho-

gonal components. The geometry of the force transducers allowed each force component to exert its own moment upon a strain gage bridge situated where the cross sectional area had been choosen to give a suitable strain for the predicted loads. The same bending beam principle was used to design the calf and ankle transducers. The ankle transducers were aligned to measure only the brace's long axis component (Y) and the calf transducers were aligned to measure only the transverse plane components (X & Z).

Transducer bodies were constructed from BOFORS RD-653 steel Svensk Norm 515 2225-5

$E = 21{,}000$ kp/mm²

$\sigma_{0,2} = 70$ kp/mm²

This material was chosen because of its high yield strength and the fact that steel is a good base material for strain gage bonding. Micro-Measurement foil gages were bonded with an epoxy cement and then heat treated. Details of construction and strain gage locations are shown for the upper segment in Fig 5a & b, and for the lower segment in Fig 6 & 7.

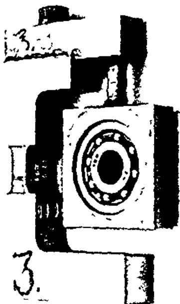


Figure 5a. Typical upper segment transducer showing mounted foil strain gages and universal coupling

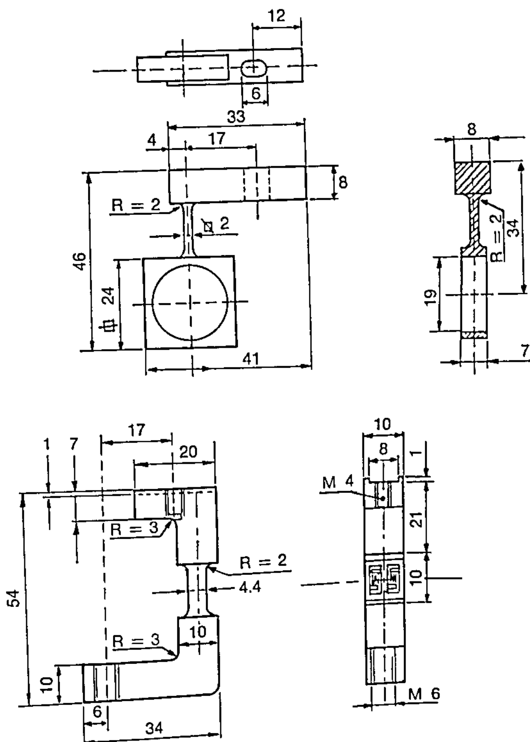


Figure 5 b Dimensions are in mm

The calf transducer bodies consist of two beams 76 mm long, 12 mm wide and 3 mm thick bolted to the anterior and lateral aspect of the middle ring of the lower segment (Fig. 7 & 12) Connection between the calf band and the transducer bodies was established by an adjustable system of bolts and locknuts. Only the force components along the X and Z axis were measured at this level since the calf band has no weight-bearing function.

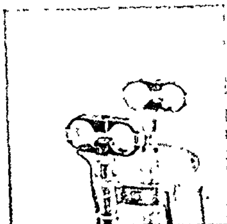


Figure 6 Ankle transducer without foot assembly

The ankle transducers were constructed using a ring design in order to measure only the force component along the Y axis Because the transducer bodies also functioned as a coupling between the brace and foot assembly, it was desirable to maintain the distance separating them as small as possible. This was accomplished by using a flattened circle configuration (Fig 6 & 7)

Interface Assemblies

Interface assemblies are composed of contour-fitted plastic shells, mounting rings and foot-ankle components

The plastic contour shells act to transmit forces between the leg and brace and to assist in maintaining alignment within the brace.

The seat and corset were cut from a 3 mm thick basic thigh shell layed up on the plaster positive mold (Fig. 8) The shell was divided into two segments, an upper 1/3 seat shell and a lower 2/3 corset shell. The upper seat perimeter was anatomically contoured (Fig 9) The anterior wall was

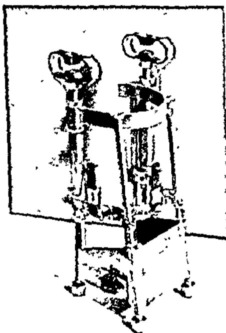
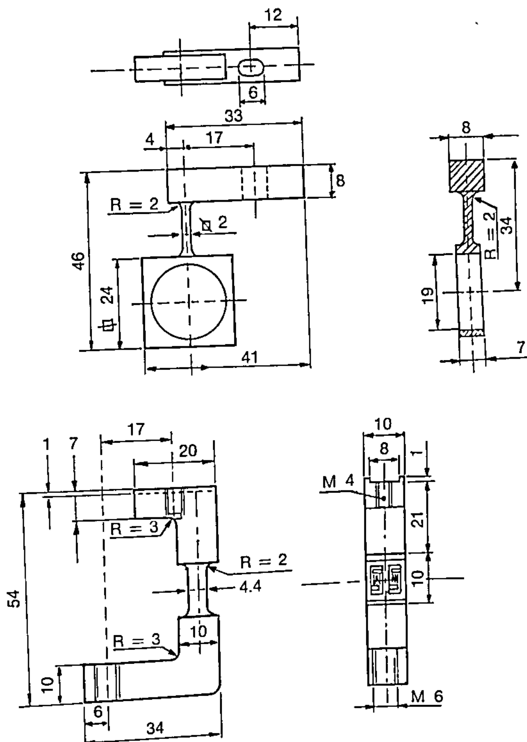


Figure 7. Lower segment upside down showing the ankle transducers, calf band beam transducers and couplings for attachment to the upper segment



BLUE PRINT OF TYPICAL
UPPER SEGMENT TRANSDUCER

Figure 5 b. Dimensions are in mm

The calf transducer bodies consist of two beams 76 mm long, 12 mm wide and 3 mm thick bolted to the anterior and lateral aspect of the middle ring of the lower segment (Fig 7 & 12) Connection between the calf band and the transducer bodies was established by an adjustable system of bolts and locknuts. Only the force components along the X and Z axis were measured at this level since the calf band has no weight-bearing function

The ankle transducers were constructed using a ring design in order to measure only the force component along the Y axis. Because the transducer bodies also functioned as a coupling between the brace and foot assembly, it was desirable to maintain the distance separating them as small as possible This was accomplished by using a flattened circle configuration (Fig. 6 & 7).



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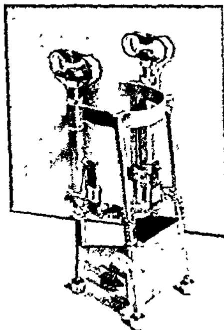
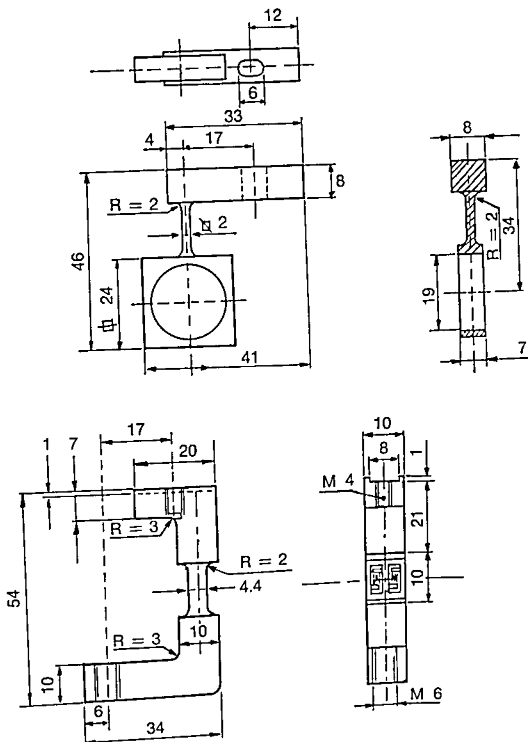


Figure 7 Lower segment upside down showing the ankle transducers, calf band beam transducers and couplings for attachment to the upper segment.



BLUE PRINT OF TYPICAL
UPPER SEGMENT TRANSDUCER

Figure 5 b Dimensions are in mm

sectioned from one seat shell to access its importance in maintaining ischial contact. Corset shells were similarly divided. Entrance and egress was accomplished through anterior longitudinal seams held closed by Velcro fasteners. The shells were fastened to the seat and corset mounting rings by four steel angle iron brackets (Fig. 10 and 11).

The mounting rings serve as attachments for the body-brace interface components and the structure by which the whole assembly is connected to the transducers. They are circular 3 mm × 40 mm aluminum argon welded units. Fastened to the outer ring surface are mounting bolts in positions corresponding to the transducers on the main brace frame. Slots were cut to receive the shell mounting bracket bolts and permit adjustments in alignment.

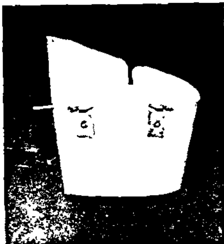


Figure 10. Seat shell with brackets ready to mount on the interface assembly ring

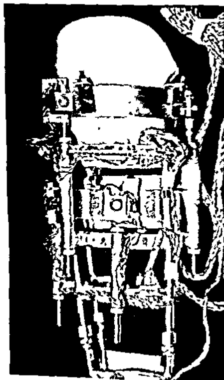


Figure 11. Seat shell mounted on the interface assembly ring



Figure 8. Basic thigh shell and segmented seat and corset shells

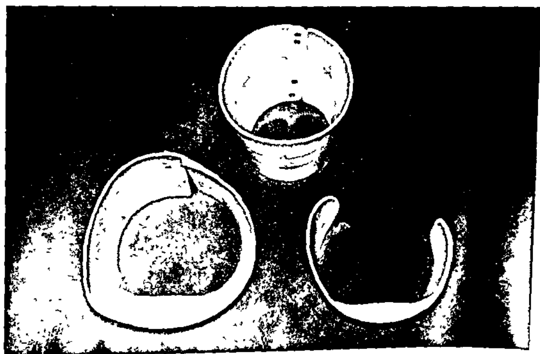


Figure 9 Above, closed corset shell Left, closed seat shell Right, open seat shell

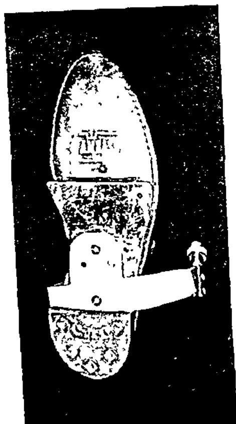


Figure 13 Shoe with steel sole plate, stirrup and rubber heel

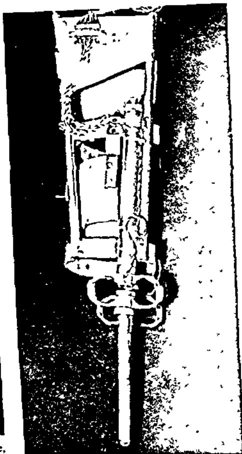


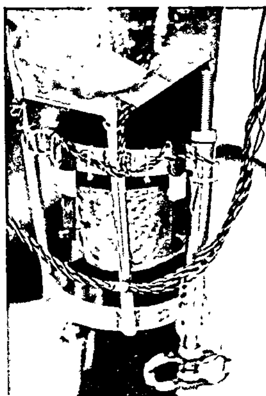
Figure 14 The caliper frame as a patten bottom

surface of the sole and extended from the heel to the metatarsal heads to provide a rigid mounting platform for the stirrup and caliper attachments To this plate were mechanically fastened the caliper or stirrup assemblies by means of an array of tapped holes which permitted different mounting positions The rubber heel was fastened in place over the selected assembly (Fig 13)

The caliper frame consisted of a 10 mm solid tubular aluminum U shaped structure which was threaded at each end for insertion into the ankle transducer bodies Alone, it functioned as a patten bottom In conjunction with a channel iron fastened to the sole plate it functioned as a caliper with heel hinge (Fig. 14 and 15)

By attaching stiffner struts between the sole plate and caliper frame arms the ankle could be fixed in selected positions of dorsiflexion neutral and plantarflexion (Fig. 15).

The stirrup assembly consisted of





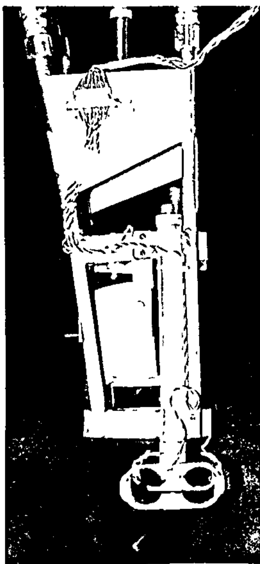
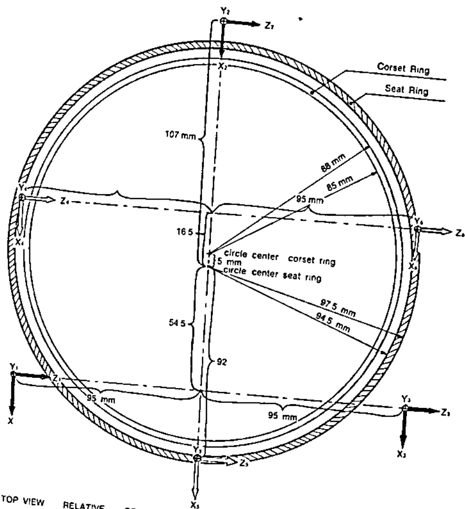


Figure 12. Details of calfband and mounting position.

The calf band consisted of a circumferential plastic laminated layup, 3 mm thick and 70 mm high with a posterior-medial entry cut, mechanically fastened to the beam transducers by two bolts (Fig 12)

The shoe assembly was fabricated from a standard low cut oxford shoe with a leather sole and rubber heel There were no orthopaedic modifications. A steel plate, 3 mm thick, was firmly riveted in place on the under



TOP VIEW RELATIVE ORIENTATION OF SEAT AND CORSET RING CENTERS

Figure 17 a

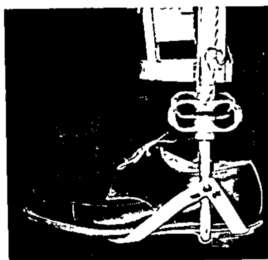


Figure 15. Shoe with caliper frame mounted in the channel iron and fixed by angle struts.

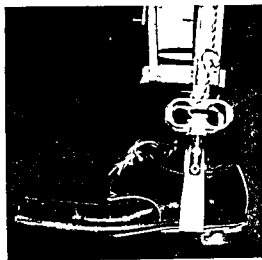


Figure 16. Shoe with stirrup assembly attached

a stainless steel U shaped base plate and two threaded mounting bolts connected by a box-type hinge. The base plate was fastened to the sole plate and the mounting bolts fastened to the ankle transducer bodies (Fig. 13 and 16).

The assembled brace lacks contouring and from a survey of ischial weight-bearing appliances in this institution, is 2—3 kg heavier. Weight without cabling is 5 kg (upper segment 3 kg, lower segment 2 kg with shoe) which was considered acceptible if the inertial forces from rapid extremity movements during gait were avoided.

There were no restrictions on leg movements other than would normally be expected in a standard long-leg brace.

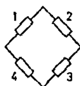
Alignment of Components

The leg with thigh shell applied was placed inside the brace frame, alignment adjusted and the sites of attachment to the interface assembly rings marked. The shell was then divided as previously described. A margin of 5 mm was left between apposing edges to prevent mutual contact. Sufficient mounting bolts, spacers and fillers were used to insure good fixation and uniform force transmission to the rings. In the standing position a plumbline passed from the middle of the ischial seat to the heel's midline and the shoe sole was flat on the floor. Fig 17 a shows the relationship of the upper and lower measuring ring centers to each other.

3 AXIS FORCE TRANSDUCER

1
STRAIN GAGÉS POSITION IN
THE WHEATSTONE BRIDGE

X=Y=Z



STRAIN GAGES:
X=Z, DIRECTION
MICRO-MEASUREMENT
EA-06-062-AQ 350 (=350 Ω)
Y, DIRECTION
MICRO-MEASUREMENT
EA-06-063-AQ 350

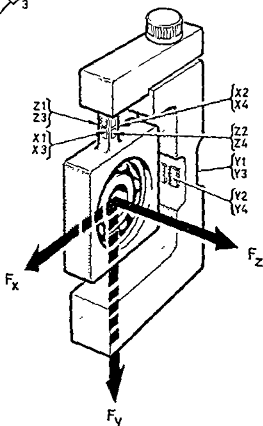


Figure 18

For computation purposes the corset ring transducer distances to the X, Y and Z axis were measured using the upper ring center as a reference (Fig. 17 b).

An over head trolly carried the electrical cable, relieving the walker of its weight and obstructing influence.

Recording Equipment

26 transducer output signals from the brace and walkway were fed into 3 recording oscillographs. Details concerning the wiring of the transducers, bridge conditioning units, galvanometer specifications and the integrated systems diagram are shown in Fig. 18, 19, 20, 21. The whole system was synchronized by a foot switch circuit which marked the analogues directly at the onset and for the duration of each foot position, heel strike, foot flat, heel off and toe off (Fig. 22).

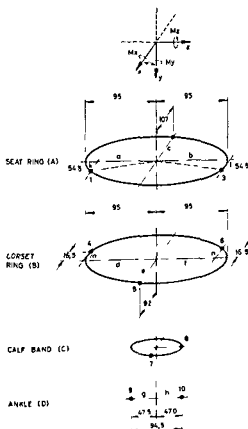


Figure 17 b Alignment of the seat and corset rings Dimensions are in mm

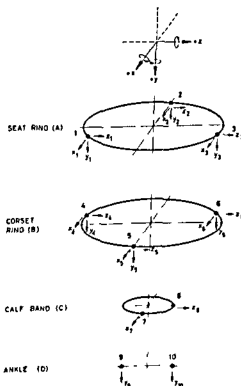
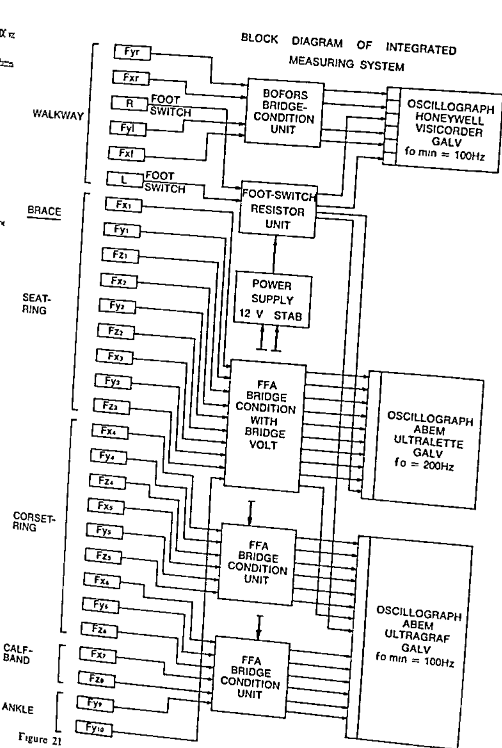


Figure 17 c Brace measuring rings, transducer locations and orientation of force vectors



BLOCK DIAGRAM OF INTEGRATED MEASURING SYSTEM
WALKWAY
Fyr
Fxr
R
FOOT SWITCH
Fyl
Fxl
L
FOOT SWITCH
BOFORS BRIDGE-CONDITION UNIT
OSCILLOGRAPH HONEYWELL VISICORDER GALV fo min = 100Hz
FOOT-SWITCH RESISTOR UNIT
POWER SUPPLY 12 V STAB
BRACE
SEAT-RING
Fx1
Fy1
Fz1
Fx2
Fy2
Fz2
Fx3
Fy3
Fz3
CORSET-RING
Fx4
Fy4
Fz4
Fx5
Fy5
Fz5
Fx6
Fy6
Fz6
CALF-BAND
Fx7
Fz8
ANKLE
Fy9
Fy10
FFA BRIDGE CONDITION WITH BRIDGE VOLT
OSCILLOGRAPH ABEM ULTRALETTE GALV fo = 200Hz
FFA BRIDGE CONDITION UNIT
FFA BRIDGE CONDITION UNIT
OSCILLOGRAPH ABEM ULTRAGRAF GALV fo min = 100Hz

Figure 21

Block diagram for one of three measured force directions (X, Y, Z).

2, 3, 4, 5 and 6.
Bridge condition units: Two 6 channels one 10 channels model FFA with stab. DC volt.

7.
Oscillographs, two. One ABEM Ultralette 10 channels. One ABEM Ultragraph 19 channels
Galvanometers with natural frequency min 100 Hz.
Flat frequency interval 0—60 Hz with

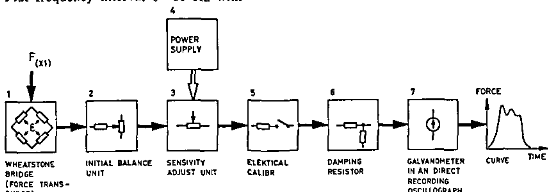
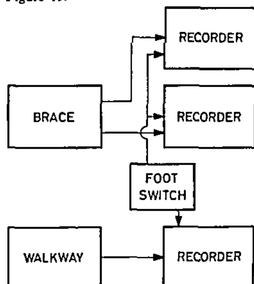


Figure 19.



BLOCKDIAGRAM OF BRACE, WALKWAY, FOOT SWITCH AND RECORDING SYSTEM

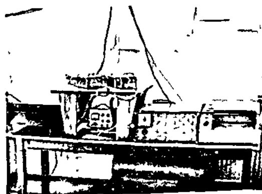


Figure 20

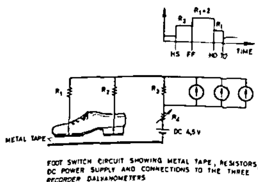


Figure 22

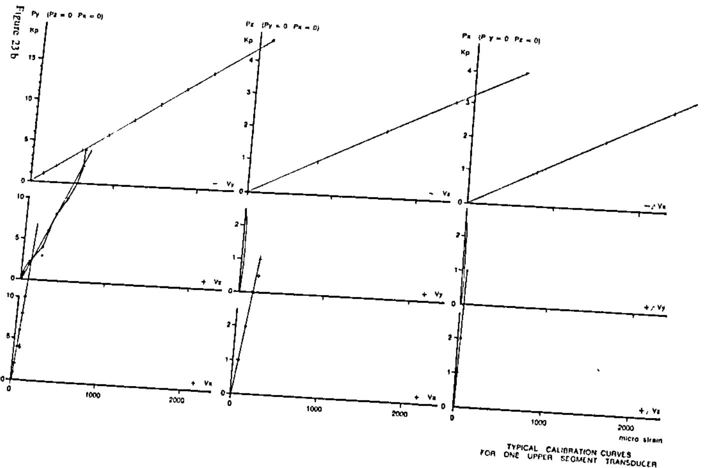

Py (Pz = 0 Px = 0)
Kp
Pz (Py = 0 Px = 0)
Kp
Px (P y = 0 Pz = 0)
Kp
1000
2000
micro strain
TYPICAL CALIBRATION CURVES
FOR ONE UPPER SEGMENT TRANSDUCER

Figure 23 b

Foot Switch Circuit

The foot switch circuit consisted of metal tape, attached to the walkway plates and heels and soles of each shoe, connected across a DC power supply, three different resistors and a galvanometer in each recorder. A step pattern of different height for each foot position appeared on the recording (Fig. 25).

Calibration

Calibration refers to the application of known loads along a specified axis of a measuring system and recording the output signals produced. From the established relationships, unknown forces applied to the system in the same direction can be quantitated. During calibration strains may be registered along axes other than the one loaded. This phenomenon is called cross sensitivity and is produced within the system by externally applied loads. The accuracy of the measurements and ability to define the applied forces requires that the cross sensitivity be small. Factors which increase cross sensitivity are related to improper transducer design, inexact mounting of the strain gages, and distortions of the mounting frame producing misorientation of the strain gages under loading.

Compared to standard braces which have been directly instrumented, the cross sensitivity error on this brace should be greatly reduced by the careful design, accurate alignment of strain gages and the rigid framework on which the transducer's parallel alignment is maintained.

Individual transducers were calibrated statically in a jig by applying loads up to 4 kp along the X and Z axis and up to 14 kp along the Y axis (Fig. 23 a). Fig. 23 b shows typical calibration curves for one transducer. Cross sensitivity was less than 5%.

The upper and lower segments were separately jigged and loaded to access the accuracy of the integrated thigh, calf and ankle measuring systems (Fig. 24). The error was found to be 5%. The two segments were not coupled and calibrated as a unit because it was assumed that each segment's stiffness properties would preclude a significant effect from being introduced as a result of the connection.

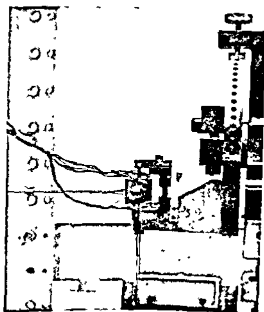


Figure 23 a An upper segment force transducer, jigged and undergoing calibration

DATA REDUCTION AND ANALYSIS

Manual reduction

Oscillograph recordings were inspected for calibration marks and then baselines for all channels were drawn. Three steps in the middle of the walk closest in time duration and force pattern were segmented into foot position and force maximum intervals (Fig. 25).

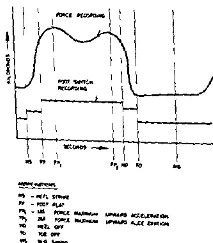


Figure 25 Segmentation of a typical force curve for digital conversion using the foot switch recording

Superimposed tracings of the channels were then drawn to confirm their similarity and facilitate comparison with other walks. One step, closest to the average of the three, was converted into digital form at each interval. Using the numerical data, equations of equilibrium Fig 26, the ring dimensions in Fig. 17 b and the sign conventions in Fig. 17 c, individual forces at the ring, calf band, and ankle units were summed and moments computed. Allowance was made for the slight offset between the corset ring center and seat ring center (Fig. 17 a).

Walkway recordings were similarly segmented and digitized. Foot positions were converted to percentages of total stance phase time. The relationship of each force maximum was determined with respect to a specific foot position. Different runs and each run, braced and unbraced sides, were compared.

The profile used for further analysis of each walk consisted of three analog force tracings, summed forces and moments and the foot-position force-peak relationships.

Test-Walking Procedure

Prior to conducting test walks, the recording equipment was allowed to warm up and then all brace and walkway channels were calibrated with a calibration resistor. The brace was applied over a single layer of stockinette and after sufficent walking to settle well into the thigh shell segments it was established that good contact existed between the ischium and seat platform by finger palpation (Orthopaedic Appliance Atlas, 1952) and that the heel was not in contact with the inner sole of the shoe.

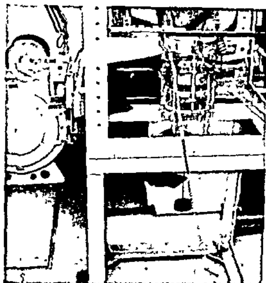


Figure 24. Assembled upper segment mounted in calibration jig. The seat ring is axially loaded to check the integrated system's response

The test walk was started two steps before contact with the walkway and ended two to three steps beyond the end of the walkway to minimize the effects of acceleration and deceleration on the force-time histories.

Walking speed was gaged to a previously established time reference from many averaged walks in the brace. This walking speed was about half the normal unbraced walking speed of the same subject. No test walk was accepted unless within 0.5 seconds of the 10 second reference and unaccompanied by accidental lurches, scrapes or scuffs.

The walk was observed by an orthopaedic surgeon, orthotist, the instrument technician and the author himself by means of a mirror situated at the far end of the walkway.

Adequate rest periods were taken between walks to eliminate fatigue variabilities on the gait pattern.

RESULTS

General interpretation

Data representing different brace variables listed in Table I was evaluated.

The walks can be divided into essentially three similar groups:

1. closed seat shell-closed corset
2. open seat shell-closed corset
3. closed seat shell-open corset

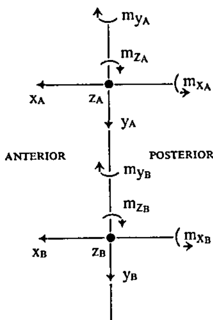
The first two groups were tested on the same day and the third group 9 days later. There were greater differences in the general results between the third and first two groups which is attributed to diurnal variables previously discussed and the greater dynamic alignment changes permitted by the reduced corset area.

Since one of the major purposes of this project was to elicit broad force envelopes it was decided to pool all runs together and compute force means and ranges. Where interesting differences were noted further amplification is presented. Foot-assembly evaluations are compared on an individual basis.

Figures 17 b and 17 c show the in-

Table 1 Walks conducted in different brace combinations.

Walk number	*Seat shell*	*Corset shell*	*Foot assembly*
1	closed	closed	patten bottom
2	closed	closed	shoe, fixed ankle, neutral
3	closed	closed	shoe, heel hinge
4	closed	closed	shoe, free ankle, internal rotation
5	closed	closed	shoe, free ankle neutral
6	closed	closed	shoe, free ankle, external rotation
7	open	closed	shoe, free ankle, external rotation
8	open	closed	shoe, free ankle, neutral
9	open	closed	shoe, free ankle, internal rotation
10	open	closed	shoe, heel hinge
11	open	closed	shoe, fixed ankle, neutral
12	open	closed	patten bottom
13	closed	none	shoe, free ankle, external rotation
14	closed	open	shoe, fixed ankle, neutral
15	closed	open	shoe, free ankle, external rotation
16	closed	open	shoe, fixed ankle, plantar flexion
17	closed	open	shoe, fixed ankle dorsiflexion
18	closed	open	shoe, fixed ankle, neutral
19	closed	open	shoe, free ankle, external rotation



$$x_A = x_1 + x_2 + x_3$$
$$y_A = y_1 + y_2 + y_3$$
$$z_A = z_1 + z_2 + z_3$$
$$m_{x_A} = b(y_3 - y_1)$$
$$m_{y_A} = b(x_3 - x_1) - a(z_1 + z_3) + c \cdot z_2$$
$$m_{z_A} = c \cdot y_2 - k(y_1 + y_3)$$

$$x_B = x_4 + x_5 + x_6$$
$$y_B = y_4 + y_5 + y_6$$
$$z_B = z_4 + z_5 + z_6$$
$$m_{x_B} = f(y_6 - y_4)$$
$$m_{y_B} = f(x_6 - x_4) - e \cdot z_5 + m(z_4 + z_6)$$
$$m_{z_B} = m(y_4 + y_6) - e \cdot y_5$$

Figure 26. Equations of equilibrium and lateral view of the free body diagram for the upper segment.

Reliability of the equipment and experimental method

The overall error can be divided into instrumentation, manual reduction and experimental method errors. These are outlined below.

1. Instrumentation error
   a) cross-sentivity error ±3%
   b) calibration error ±5%
   c) recorder drift ±2%
   d) recorder errors within the flat frequency range used ±2%
2. Manual reduction error ±3%
3. Variability in the experimental method ±5%

Apart from the brace performance, force variations between walks can occur from a change in body weight, fatigue, removal and application times for the apparatus, normal step to step and day to day diurnal differences in gait pattern. Appoldt & Bennett (1968) studied the effect of these variables during investigations of AK stump-socket pressures and found that they could cause a scatter of ±10% about the mean values. This variability was minimized when test runs were conducted on the same day.

During this project the subject's weight remained constant at 61 kp, adequate rest periods were observed, the apparatus on and off time was never more than 15 minutes, most of the test runs were conducted on the same day and the remainder within the next 9 days. Because of these precautions the scatter effect is estimated to be less than 5%. It is unlikely that all errors will combine simultaneously in the same direction to produce an error as large as 20%. A realistic estimate of the measuring error is considered to be ±10% (Hetenyi, 1963).

RESULTS

General interpretation

Data representing different brace variables listed in Table 1 was evaluated.

The walks can be divided into essentially three similar groups:

1. closed seat shell-closed corset
2. open seat shell-closed corset
3. closed seat shell-open corset

The first two groups were tested on the same day and the third group 9 days later. There were greater differences in the general results between the third and first two groups which is attributed to diurnal variables previously discussed and the greater dynamic alignment changes permitted by the reduced corset area.

Since one of the major purposes of this project was to elicit broad force envelopes it was decided to pool all runs together and compute force means and ranges. Where interesting differences were noted further amplification is presented. Foot-assembly evaluations are compared on an individual basis

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6	closed	closed	shoe, free ankle, external rotation
7	open	closed	shoe, free ankle, external rotation
8	open	closed	shoe, free ankle, neutral
9	open	closed	shoe, free ankle, internal rotation
10	open	closed	shoe, heel hinge
11	open	closed	shoe, fixed ankle, neutral
12	open	closed	patten bottom
13	closed	none	shoe, free ankle, external rotation
14	closed	open	shoe, fixed ankle, neutral
15	closed	open	shoe, free ankle, external rotation
16	closed	open	shoe, fixed ankle, plantar flexion
17	closed	open	shoe, fixed ankle dorsiflexion
18	closed	open	shoe, fixed ankle, neutral
19	closed	open	shoe, free ankle, external rotation

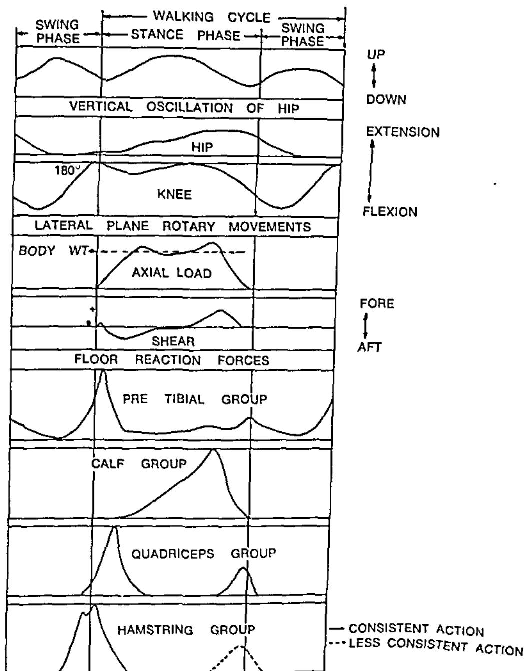

WALKING CYCLE
SWING PHASE
STANCE PHASE
SWING PHASE
UP
DOWN
VERTICAL OSCILLATION OF HIP
EXTENSION
HIP
180°
KNEE
FLEXION
LATERAL PLANE ROTARY MOVEMENTS
BODY WT
AXIAL LOAD
FORE
AFT
SHEAR
FLOOR REACTION FORCES
PRE TIBIAL GROUP
CALF GROUP
QUADRICEPS GROUP
HAMSTRING GROUP
CONSISTENT ACTION
LESS CONSISTENT ACTION
IDEALIZED MUSCLE ACTION CURVES (95 STEPS/MIN)
CORRELATION OF PHASIC MUSCLE ACTIVITY WITH JOINT DISPLACEMENTS AND FLOOR REACTION FORCES
FROM UNIVERSITY OF CALIFORNIA PROSTHETIC DEVICES RESEARCH 1947

Figure 27.

dividual transducer locations, mounting ring positions, important dimensions and the sign conventions used. All forces are expressed in kp and moments in kp-mm. Unless otherwise stated forces are interpreted as acting on the brace. Reactions on the leg are equal and opposite in direction.

General concepts used in the analysis of results are illustrated in the consideration of axial loading during stance and swing phase. During stance phase axial forces registered at the ankle transducers indicate the combined effect of body weight, brace weight above the ankle, muscular activity within the brace and ground reaction. In order to separate bodyweight forces from muscle-activity forces it is necessary to look at that part of the cycle where the other's contribution is minimal. The brace weight is assumed constant From EMG studies reported (Eberhart et al., 1947) muscle activity is greatest during late stance-early swing and late swing-early stance corresponding to the periods of acceleration, deceleration and weight-acceptance stability (Fig 27)

During the middle part of stance phase the body is riding foward on the brace and weight-bearing loads are maximal.

Toe clearance is normally accomplished by hip and knee flexion and ankle dorsiflexion. In the test brace with a locked knee, toe clearance depended on circumduction, hiking of the pelvis and ankle dorsiflexion, when the ankle was free. During swing phase the ankle transducer forces reflect the brace weight not suspended from the upper thigh, shoe assembly wt. 0.8 kg, upward accelerating forces from the foot if distal migration of the brace has occured at toe off and forces caused by any attempted hip, knee or foot motion against the confines of the apparatus.

Muscle forces are expected to exert their greatest effect on the system during late stance-early swing and late swing-early stance, while maximal weight bearing forces occur during mid stance when the upward accelerations are taking place (FP1, FP2). This means that the best part of stance phase to evaluate a test brace's weight-relieving effectiveness, irrespective of muscle loading, is between foot flat and heel off.

The axial loading patterns recorded throughout the gait cycle are a result of these interactions. By similar analogy somewhat lesser forces appear along the X and Z axis.

Abbreviations used in the text

HS = heel strike
FF = foot flat
FP1 = 1st vertical floor maximum
FP2 = 2nd vertical floor maximum
HO = heel off
TO = toe off
MS = mid swing

Gait Pattern

The subject's, i e. the author's, gait was evaluated by an orthopaedic surgeon, the orthotist in charge of the brace workshop and the author who could observe himself in a mirror at

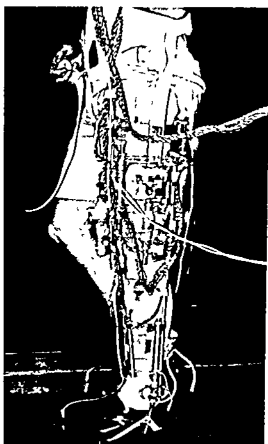


Figure 28. *Lateral view.*
Author in the brace during mid stance phase. Note foot-switch circuit wiring attached to the shoes



Figure 29. *Front view.*
Just before heel strike. Note pelvic hiking on the normal side.

the end of the walkway. The typical gait pattern displayed slight vaulting during stance phase on the braced side. Toe clearance during swing phase was accomplished by ankle dorsiflexion and circumduction on the braced side and pelvic hiking on the opposite side. Viewed from in front, the stance phase was abducted 0—5 deg., and from the side the long axis of the brace was inclined posteriorly from the vertical 14 deg. at heel strike decreasing to 7 deg. at toe off (Fig 28, 29, 30).



Figure 30 *Posterior view*
Heel strike on the braced side Metal tape is on the walkway plates and shoe heels completing the foot-switch circuit

MEAN LOADING TRENDS

Axial loading (Y) Table 2, Fig. 31

Axial forces were exerted throughout the gait cycle, including swing phase, except with a patten bottom frame. This is explained by the fact that brace combinations with a shoe were loaded by forces transmitted from foot movements within the shoe.

In the patten bottom brace forces could not be transmitted to the brace because the foot was unattached to the patten frame.

Anterior-posterior loading (X)

During the period heel-strike-to-first-force maximum the largest forces were recorded in the seat shell and were directed posteriorly. The thigh shell resultant is posteriorly directed and probably reflects the acceleration of the upper thigh against the posterior wall (Appoldt & Bennett, 1968). At the second force maximum the resultant became anterior and then posterior at heel off and mid swing. The AP thigh shell and calf band force distribution during swing phase correlates with the angular moment necessary to accelerate the leg in the line of progression.

Table 2 Range of forces (kp) during ambulation Body weight is 61 kp

	UP-DOWN		MEDIAL-LATERAL		POSTERIOR-ANTERIOR	
seat	− 1.0	+39 0	−2.5	+10 5	−20 0	+ 4 2
corset	−10 5	+15 5	−6 7	+ 0 8	− 6.7	+ 9 0
calf	force not measured		−6 0	+10 0	− 7 0	+10 0
ankle	0 0	+7 0	forces not measured			
floor	0 0	+7 7	forces not measured			

Medial-lateral loading (Z)

Seat and calf forces were lateral and opposite to the corset forces and produced a medial bending effect against the brace and shearing forces against the leg. Possible causes of this phenomenon are the normal valgus thrust of the knee (Perry 1967) and vertical loading of the brace in abduction.

Loading From Muscle Forces

Loading was produced on the brace by attempted hip, knee and foot motion while standing non weight bearing (Fig. 32). Since the brace is rigid and attached to both ends of the limb, axial shortening or lengthening loads caused by attempted joint motion will produce opposite tensile and compressive loads on the brace and leg.

Non weight-bearing forces along the brace's axis were recorded before and during the applied forces from attempted joint motion. Longitudinal before-loading values ranged from 2—7 kp indicating the weight of the brace plus the presence of unavoidable muscle activity. Plantar flexion produced a compressive instead of the expected tensile effect which can be explained by a slightly anterior alignment of the ankle joint with respect to the caliper frame (Table 3).

Mean Moments

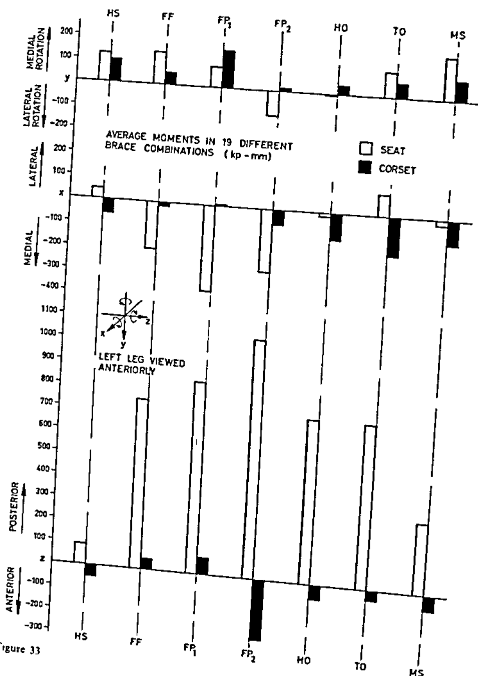
Moments are expressed in kp-mm units (Fig. 33) and interpreted as being applied to the brace.

Torsional moments

Torsional moments about the longitudinal brace axis (Y) were internally directed from heel strike to the first force maximum. They became external at the second force maximum and then internal again during swing phase. This sequence correlates with the pattern of transverse intersegmental moments generated by an unbraced limb, but is smaller in magnitude (Murdoch, 1970).

Table 3. Loading (kp) due to attempted joint motion while standing non weight bearing

Attempted motion		*Before loading*	*during loading*	*muscle force*	*net effect brace*	*net effect limb*
Hip	flexion	6	7	+1	compression	tension
	extension	6	10	+4	compression	tension
Knee	flexion	6	15	+9	compression	tension
	extension	7	5	—2	compression	tension
ankle	dorsiflexion	4	7	+3	compression	tension
	plantarflexion	3	4	+1	compression	tension
	fixed	3	7	+4	compression	tension
	free	2	2	0	none	none
	supination	2	4	+2	compression	tension
	pronation					



HS
FF
FP1
FP2
HO
TO
MS
MEDIAL ROTATION
LATERAL ROTATION
200
100
y
-100
-200
AVERAGE MOMENTS IN 19 DIFFERENT BRACE COMBINATIONS (kp - mm)
SEAT
CORSET
LATERAL
MEDIAL
x
-300
-400
1100
1000
900
800
700
600
500
400
300
LEFT LEG VIEWED ANTERIORLY
POSTERIOR
ANTERIOR
z

Figure 33

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	extension	7	5	—2	compression	tension
ankle	dorsiflexion					
	plantarflexion	4	7	+3	compression	tension
	fixed	3	4	+1	compression	tension
	free	3	7	+4	compression	tension
	supination	2	2	0	none	none
	pronation	2	4	+2	compression	tension

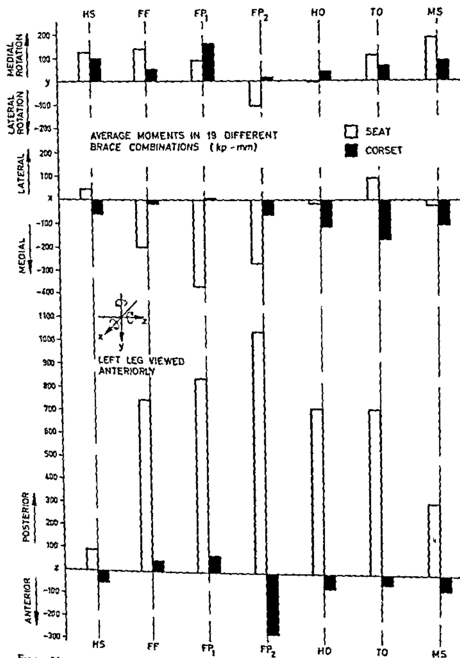

HS
FF
FP1
FP2
HO
TO
MS
MEDIAL ROTATION
LATERAL ROTATION
200
100
y
-100
-200
AVERAGE MOMENTS IN 19 DIFFERENT
BRACE COMBINATIONS (kp-mm)
SEAT
CORSET
LATERAL
MEDIAL
x
-300
-400
1100
1000
900
800
700
600
500
400
300
LEFT LEG VIEWED
ANTERIORLY
POSTERIOR
ANTERIOR
z

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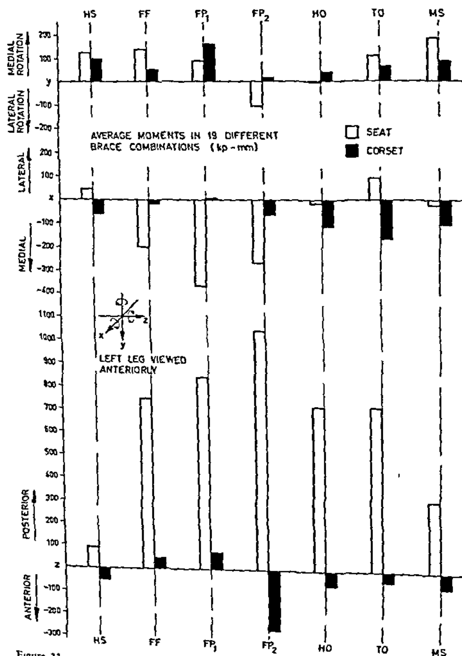
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	free	3	7	+4	compression	tension
	supination	2	2	0	none	none
	pronation	2	4	+2	compression	tension



HS
FF
FP_1
FP_2
HO
TO
MS
MEDIAL ROTATION
LATERAL ROTATION
200
100
y
-100
-200
AVERAGE MOMENTS IN 19 DIFFERENT BRACE COMBINATIONS (kp-mm)
SEAT
CORSET
LATERAL
MEDIAL
x
-300
-400
1100
1000
900
800
700
600
500
400
300
LEFT LEG VIEWED ANTERIORLY
POSTERIOR
ANTERIOR
z

Figure 33

Anterior-posterior moments

The large posterior moments exerted on the seat shell were caused by body weight forces applied to the ischial platform, which is posterior to the medial-lateral (Z) axis of rotation. In addition, a small downward component is provided from forward flexion of the pelvis during early swing phase (Strohm et al., 1963).

Medial-lateral moments

During mid stance medial moments are exerted primarily on the seat shell, which correlates with the greater axial loading on the medial side of the brace. At heel strike and toe off seat moments became lateral possibly reflecting the preparatory movements of the body to meet these transitional phases.

Table 4.

Moments about ring axis closed seat and corset shells		*HS*	*FF*	*FP1*	*FP2*	*HO*	*TO*	*MS*
				Σmy (kp-mm)				
Patten bottom	Seat	167		628	483		1346	1218
	Corset	168		167	224		148	231
Fixed ankle	Seat	145	29	72	—275	— 26	31	107
	Corset	432	83	1661	73	101	148	149
Caliper heel hinge	Seat	191	116	72		— 28	34	209
	Corset	178	45	101		101	119	178
Ankle hinge	Seat	104	— 18	— 31		4	94	145
	Corset	120	101	119		52	109	176
				Σmx (kp-mm)				
Patten bottom	Seat	— 95		—570	—760		570	190
	Corset	—238		—380	—380		—475	—285
Fixed ankle	Seat	95	— 95	—475	—380	— 95	143	95
	Corset	0	— 95	—570	—285	—238	—285	— 95
Caliper heel hinge	Seat	48	—285	—380		10	143	48
	Corset	— 95	— 48	— 48		—238	—475	— 95
Ankle hinge	Seat	— 95	—285	—665		— 95	— 48	—190
	Corset	—285	—285	—171		—475	—380	—380
				Σmz (kp-mm)				
Patten bottom	Seat	— 30		2023	2239		105	107
	Corset	—100		93	139		17	— 17
Fixed ankle	Seat	265	1329	1541	525	584	558	156
	Corset	289	37	1695	—168	—130	—155	— 76
Caliper heel hinge	Seat	132	901	953		638	560	292
	Corset	17	—143	—126		146	—109	— 76
Ankle hinge	Seat	— 59	685	790		693	774	210
	Corset	17	182	234		17	33	33

Interpretation of moments

Table 4 lists the moments about the X, Y, Z axes of the upper segment's measuring rings in four closed seat shell braces with different foot assemblies Where no moments are listed under FP2 it means that no definite FP2 existed on the ankle force tracing. Patten bottom braces do not have a FF or HO phase.

Pooled trends have been shown in Fig 33 It is evident that the moments are different in each segment and vary during the gait cycle The greatest moments were exerted when the forces along the Y axis were largest. Moments were largest in patten bottom combinations and occured primarily on the seat shell With shoe assemblies the moments were less because part of the weight bearing forces responsible for the moments shunted through the limb directly to the ground During mid stance phase more loading was transferred to the corset and the moments acting on this segment increased.

LOADING DISTRIBUTION WITHIN THE BRACE

Weight relief refers to the amount of body weight transfered to the brace. By comparing the ankle transducer recordings with the body weight of 61 kp it is possible to assess the unweighting effectiveness of a particular test brace Fig 34 compares 8 different brace combinations, closed and open seat shell types, each with 4 different foot assemblies Weight transfer was complete in the patten bottom braces which is expected since there is no foot-ground contact. The other combinations displayed a progressively lower FP2 loading in the fixed, heel-hinge and free-ankle combinations respectively which suggests that the skeletal loading increased as the subject rolled forward into his metatarsal heads. All combinations except the patten bottom types displayed a progressive decrease in unweighting toward the latter part of stance phase.

Fig. 35 compares the three groups with different thigh-shell configurations in free and fixed ankle assemblies. Although the group with an open corset was tested with a nonabducted gait, the marked difference in loading recorded is primarily attributed to the small corset segment which is unable to accept any weight transfer

Comparative load distribution in the medial and lateral uprights

Comparative loading of the medial and lateral uprights was studied at the ankle level for abducted and non abducted gait patterns (Fig 35) The lateral upright loading was smaller and of a different pattern than the medial upright During the loading period foot-flat-to-force-maximum-two, abducted gait produced 3—7 times greater axial forces on the medial upright This asymmetry was not present during the same period in non-abducted walking.

Level of weight transfer

The closed seat and open seat shell

Anterior-posterior moments

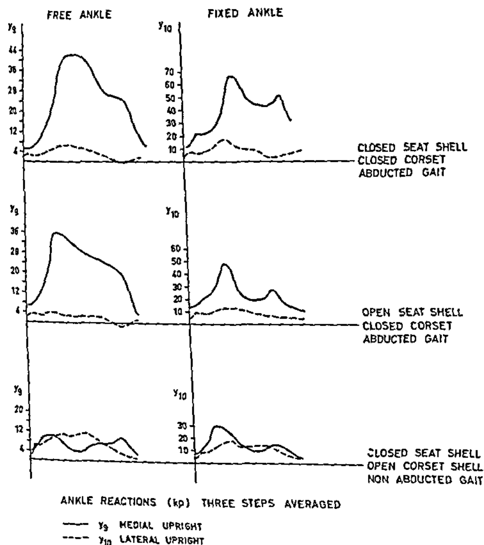
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	Corset	120	101	119		52	109	176
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Caliper heel hinge	Seat	48	—285	—380		10	143	48
	Corset	— 95	— 48	— 48		—238	—475	— 95
Ankle hinge	Seat	— 95	—285	—665		— 95	— 48	—190
	Corset	—285	—285	—171		—475	—380	—380
				Σmz (kp-mm)				
Patten bottom	Seat	— 30		2023	2239		105	107
	Corset	—100		93	139		17	— 17
Fixed ankle	Seat	265	1329	1541	525	584	558	156
	Corset	289	37	1695	—168	—130	—155	— 76
Caliper heel hinge	Seat	132	901	953		638	560	292
	Corset	17	—143	—126		146	—109	— 76
Ankle hinge	Seat	— 59	685	790		693	774	210
	Corset	17	182	234		17	33	33


FREE ANKLE
FIXED ANKLE
Y9
Y10
44
36
28
20
12
4
70
60
50
40
30
20
10
CLOSED SEAT SHELL
CLOSED CORSET
ABDUCTED GAIT
Y9
Y10
36
28
20
12
4
60
50
40
30
20
10
OPEN SEAT SHELL
CLOSED CORSET
ABDUCTED GAIT
Y9
Y10
20
12
4
30
20
10
CLOSED SEAT SHELL
OPEN CORSET SHELL
NON ABDUCTED GAIT
ANKLE REACTIONS (kp) THREE STEPS AVERAGED
Y9 MEDIAL UPRIGHT
Y10 LATERAL UPRIGHT
Figure 35

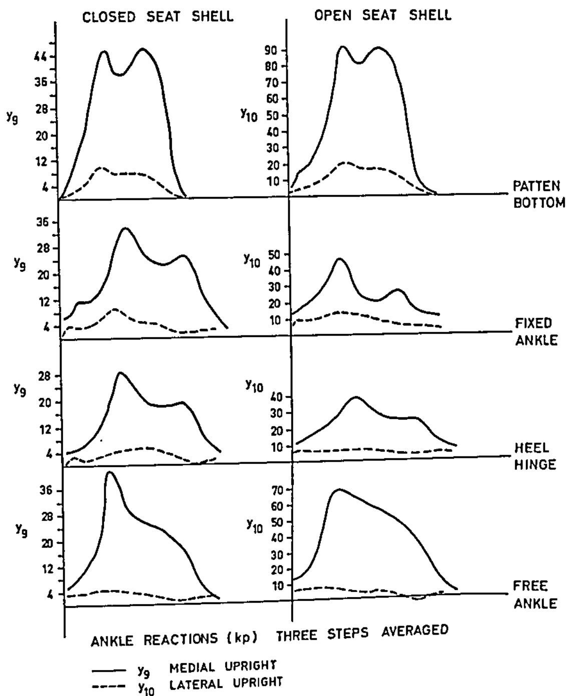
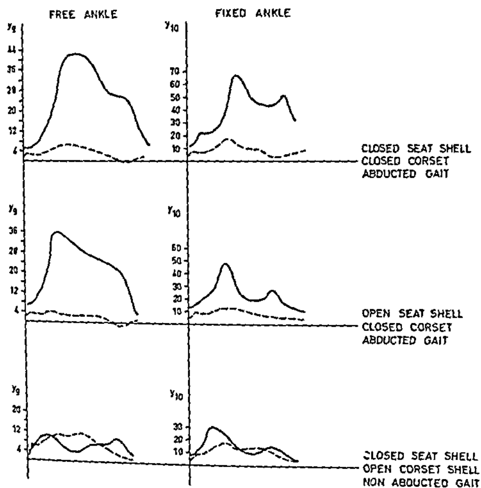

CLOSED SEAT SHELL
OPEN SEAT SHELL
y9
y10
PATTEN BOTTOM
FIXED ANKLE
HEEL HINGE
FREE ANKLE
ANKLE REACTIONS (kp) THREE STEPS AVERAGED
y9 MEDIAL UPRIGHT
y10 LATERAL UPRIGHT

Figure 34.



ANKLE REACTIONS (kp) THREE STEPS AVERAGED

—— y_9 MEDIAL UPRIGHT

----- y_{10} LATERAL UPRIGHT

Figure 35

brace combinations were pooled, the average seat and corset forces computed and then expressed as a percentage of the total thigh shell load (Fig. 36).

In all cases the greatest percentage of the total thigh shell load was borne by the seat shell. However, in the open seat shell types without an anterior retaining wall, ischial contact was decreased resulting in more weight being transferred to the corset. This is shown by the corresponding increase in load percentage on the corset.

Calf band forces

Calf band forces along the X and Z axis were recorded for selected runs and their patterns compared with different foot assemblies for different alignments. Although signs sometimes differ between the test-brace patterns, the overall force trends are similar for similar braces. Group III differed more than groups I and II and is most likely explained by the changes in leg alignment permitted by the diminitive corset segment during dynamic loading.

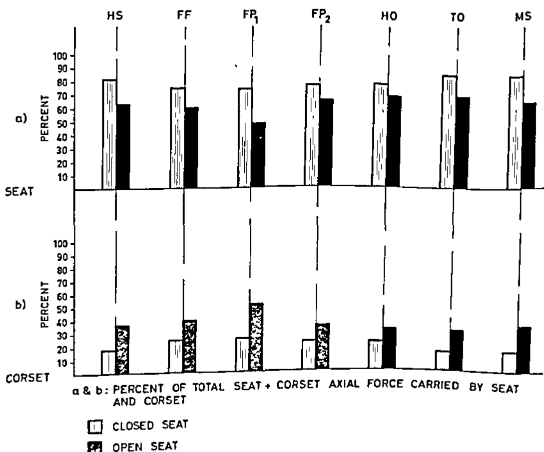


Figure 36

Free ankle — Rotational Alignment

Free ankle force patterns are shown in Fig 34, 35 and 37. Fig. 37 compares the effect of changing rotational alignment of the stirrup and illustrates the general force trends. At heel strike the leg is exerting anterior forces against the calf band. This pattern became progressively posterior and lateral peaking at the first vertical floor maximum. As the leg begins to pivot forward it produces more anterior calf band forces again which peak just before toe off. Different rotational alignments showed essentially similar force trends.

Free and fixed ankle combinations

Free and fixed ankle combinations were compared in the test brace having a closed seat shell and open corset shell. The essential differences be-

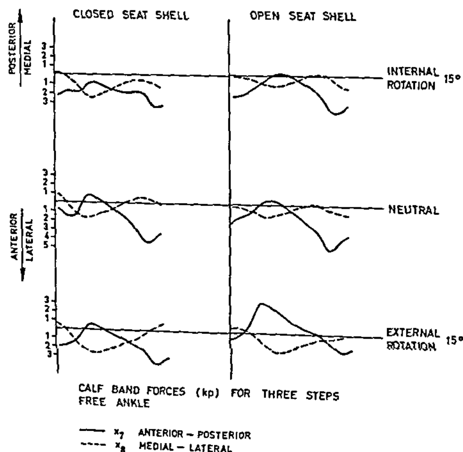


Figure 37

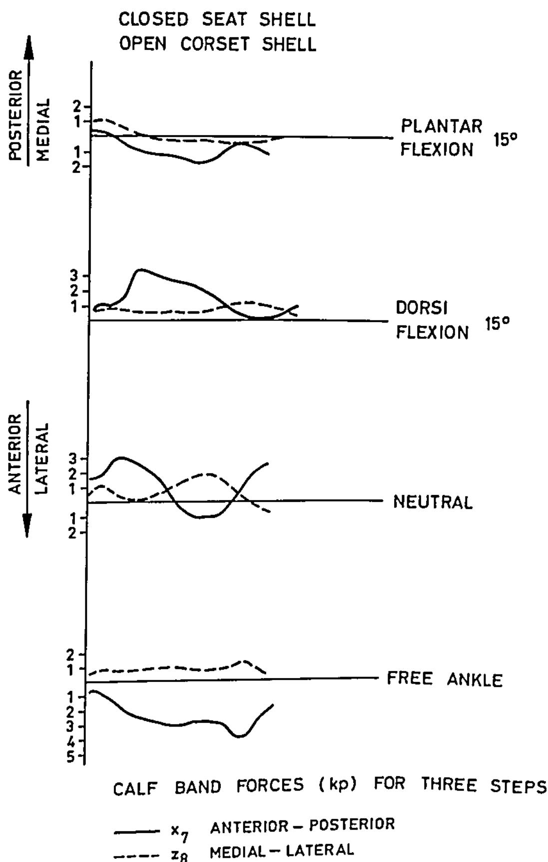
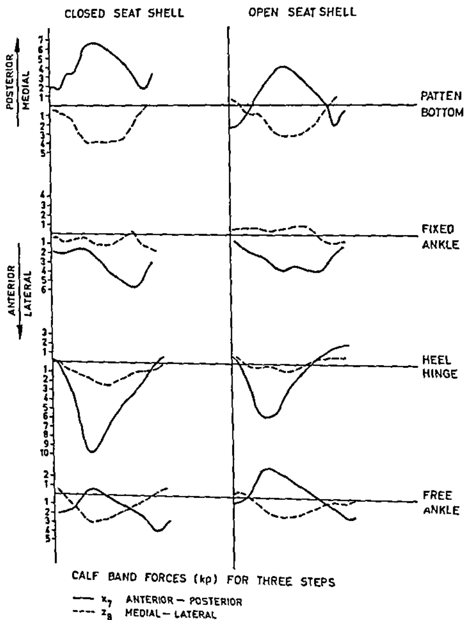

CLOSED SEAT SHELL
OPEN CORSET SHELL
POSTERIOR
MEDIAL
ANTERIOR
LATERAL
PLANTAR FLEXION 15°
DORSI FLEXION 15°
NEUTRAL
FREE ANKLE
CALF BAND FORCES (kp) FOR THREE STEPS
x_7 ANTERIOR – POSTERIOR
z_8 MEDIAL – LATERAL

Figure 38



CLOSED SEAT SHELL
OPEN SEAT SHELL
POSTERIOR
MEDIAL
ANTERIOR
LATERAL
PATTEN BOTTOM
FIXED ANKLE
HEEL HINGE
FREE ANKLE
CALF BAND FORCES (kp) FOR THREE STEPS
x7 ANTERIOR — POSTERIOR
z8 MEDIAL — LATERAL

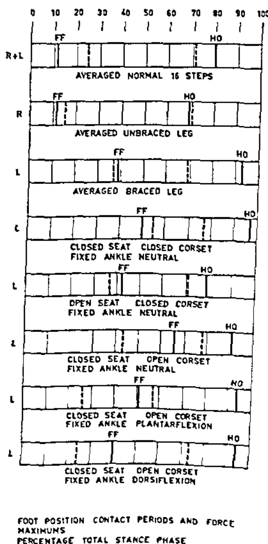
Figure 39

tween fixed and free ankles are the lack of plantar flexion at heel strike and dorsiflexion (toe clearance) at toe off. This problem is less for the fixed plantar flexed position at heel strike and the fixed dorsiflexed position at toe off. Hence one would expect to see similar force trends, compared to a free ankle, at the beginning and end of stance phase with plantar flexed and dorsiflexed positions respectively. These predictions are substantiated in Fig. 38.

Comparison of four standard foot assembles

Different foot assemblies consisting of a patten bottom, fixed ankle (neutral), caliper heel hinge and a free ankle (15 deg. of ext rotation) were compared with the two basic thigh-shell configurations (Fig. 39). The free and fixed ankle patterns have already been described. A heel caliper hinge is eccentrically located compared to the anatomic ankle joint. During plantarflexion the leg presses forward against the calf band, while dorsiflexion produces an opposite posterior force. This effect is demonstrated by a 10 kp sharp anterior force peak occuring with plantarflexion and just before the first force maximum As the leg pivots forward and ankle dorsiflexion begins, these forces reverse but are not as large. The 10 kp reaction force exerted posteriorly against the anterior tibial border would produce an extension moment about the knee.

In the patten bottom brace type distal alignment of the leg was maintained by the calf band alone. The posterior force peak corresponds to the first force maximum. As the leg pivots forward the posterior force decreases and in the open seat became positive near toe off.



FOOT POSITION CONTACT PERIODS AND FORCE MAXIMUMS
PERCENTAGE TOTAL STANCE PHASE
---- (FORCE MAXIMUM) FP_1, FP_2

Figure 40

FOOT-POSITION AND FLOOR MAXIMUM RELATIONSHIPS

Floor-contact periods for each foot position and the timing of FP1 and FP2 for all steps in each walk (except the first and last) were determined, averaged and expressed as a percentage of the total stance phase time. The results were compared against averaged walks without the brace and between the braced and unbraced sides for each walk (Fig. 40). Compared to unbraced gait, with the left leg braced, the right side showed an earlier FP1, longer HO-TO, and FP2 closer or within HO-TO. The braced leg demonstrated a longer HS-FF, FP1 close to or within HS-FF, shorter HO-TO and earlier FP2 in FF-HO. The greatest changes occured with fixed ankle combinations where HS-FF was prolonged with FP1 usually occuring well within this period indicating that the full impact of weight acceptance was borne on the heel.

DISCUSSION

The data presented was obtained from the force-time histories recorded with an instrumented test brace capable of simulating selected ischial weight-bearing brace combinations. The appliance was 2—3 kg heavier than standard designs, less flexible and lacked contouring. These differences arose from the construction details which were necessary to achieve a lower instrumentation error and a greater versatility. The instrumentation and test methods proved to be a suitable tool for investigating the variables outlined. Because one normal subject was used his biomechanical interactions with the brace are not considered necessarily representative of other normal subjects or patients requiring orthoses. However, the force patterns and envelopes described have helped to take a closer look at the effectiveness of certain general bracing techniques and learn more about the load distribution within brace structures. The net effect on the leg is determined from an analysis of these findings.

Floor contact patterns

Small changes in the duration of the foot positions and force-peak timing, not readily observable, were detectable by the foot switch circuit.

A normal gait without the brace, but at the same test speed showed the first force peak to occur in early Foot-Flat-to-Heel-Off phase, permitting the upward acceleration of the trunk to be applied gradually and distributed more evenly over the foot. With fixed ankle assemblies, the Heel-Strike-To-Foot-Flat period was prolonged and contained the first force maximum which indicates that the full impact was borne on the heel.

Loading distribution in the brace

Weight relief means the transference of body weight to the brace's structures. The location of this transference determines the level of skeletal unloading. Thigh shells with an anterior wall in the seat segment carried a more proximal distribution of the total load This indicates that an anterior wall is important in order to maintain optimal ischial contact with the seat platform.

On the braces with different foot assemblies which were evaluated, the patten bottom types provided complete weight transference during stance

phase, however they are uncomfortable and present instability problems (Lehmann et al, 1970) The braces with shoe combinations demonstrated lesser degrees of weight-relieving effectiveness. Although the fixed ankle with metal sole plate is considered necessary to reduce metatarsal head loading during late stance phase, in this study it actually was associated with greater loading than with the free ankle. Variability between runs could account for this apparent paradox but another contributing factor may be the unseating effect produced by a greater jolt at heel strike.

Swing phase loading patterns were recorded on the brace and suggested a contribution from muscle activity. The same interpretation has been reported by other workers (Kirkpatrick et al, 1969 and Magora et al., 1968). Consequently, investigations were undertaken to evaluate this possibility. Loading against the confines of the apparatus showed that the largest forces were produced with knee flexion, hip flexion-extension and ankle dorsiflexion plantarflexion in that order That muscle forces of some magnitude can occur in a partially immobilized limb is supported by Schenck's et al (1969) studies on instrumented short-leg plaster casts He found that stresses were often higher during swing phase than stance phase

It is concluded that the axial swing phase loading resulted from muscle activity plus any brace weight above the transducers not suspended by interface friction with the leg Swing phase axial loading was not seen in the patten bottom types where ankle motion was independent of the brace. Forces were exerted on the braces with a shoe assembly connected. Assuming equal suspension forces at the thigh shell interfaces, and the presence of patterned ankle dorsiflexion to provide toe clearance, this loading must have been caused by muscle forces transmitted from foot movements within the shoe.

Unequal loading

The greater loading of the medial upright in a slightly abducted gait suggests that lighter designs might be possible using a single medial upright or lighter lateral upright.

The abducted gait and normal valgus thrust of the knee (Perry 1967) are considered to be the main causes of the bending loads recorded by the brace.

Comparison of calf band force patterns produced with a caliper and ankle hinge showed a marked difference Calipers are normally inserted in the heel region which is poorly aligned with the anatomic ankle joint. During ambulation in a short leg brace this malalignment is usually not a problem because the eccentric rotations are converted to a compensatory sliding motion up and down the calf. In the long-leg test brace this compensatory motion was not possible. Instead, the lower leg was pressed anteriorly against the calf band with forces ranging up to 10 kp during plantar flexion. Since the reac-

tion against the leg is posterior, a concomitant extension moment at the knee is produced. The possibility of using this moment to dynamically stabilize a weak knee in early stance phase is suggested.

That moment differences occured between the seat and shell segments is partly related to the dynamic interactions influencing the leg and whole brace, partly to the changing force distributions which occured between the shell segments during the gait cycle and partly to the additional forces applied above the hip by the pelvis to the seat-shell extensions. The significance of these differences clinically with respect to the effects on the contained thigh segment is not entirely clear. Further, shell forces applied to the thigh's soft tissues are not necessarily transmitted wholly to the underlying femur. If rotational stability is desired, such as to protect a femoral fracture, then torque applied to or by the braced leg should be exerted proximally (in order to by-pass the fracture).

From a comparison of torque distributions in the seat and corset shell segments of different test brace combinations it is apparent that the largest and most proximally exerted torques were produced when brace loading was greatest at the seat. Thus, in order to concentrate the applied torques proximal to a femoral shaft fracture, thereby enhancing rotational stability, a long-leg brace used for ambulatory fracture treatment should provide ischial weight-bearing capabilities.

Inadvertant swiveling of the braced leg on its heel with the attendant torque effect can be minimized by shortening the Heel-Strike-To-Foot-Flat period. Since fixed ankles prolong this susceptible period a free ankle should be used when torque effects must be avoided.

The effects of a disparity in anterior-posterior or medial-lateral moments is more difficult to evaluate. Because the leg and brace are assumed to be in equilibrium one moment must be counterbalanced by another. The large posterior moment demonstrated at the seat must be counterbalanced somewhere more distally on the thigh. For a recent fracture this could have either a stabilizing or disrupting influence depending on the fracture level. If dynamic stabilization of fractures is possible it will be accomplished by providing the proper moment and force interactions against the fragments.

SUMMARY AND CONCLUSIONS

1. Research in the field of lower extremity orthotics is hampered by a lack of quantitative clinical data which is necessary to correlate clinical findings with a particular brace.
2. Clinical evaluation of a lower extremity orthotic device used during ambulation must be supplemented by a quantitative analysis to understand the biomechanical nature of the interacting systems.
3. The test brace and experimental method herein described has proved to be a useful research tool in acquiring force-time histories on testwalks representing ischial weight-bearing brace combinations worn by the author.
4. Body weight transmission to the brace was complete only in the brace types with a patten bottom. Brace combinations with shoe attachments failed to completely unload the leg and became progressively more ineffective toward the latter part of stance phase. This resulted partly from incomplete transmission of bodyweight to the brace and partly from patterned muscle activity against the confines of the apparatus.
5. An anterior (closed) seat-shell wall is necessary to maintain effective ischial platform contact. Closed seat thigh shells demonstrated more proximal and more effective weight relief than the open seat thigh shell brace types tested.
6. Muscle forces voluntarily exerted against the confines of the brace with a shoe attachment were documented. Their role in producing swing phase loading was established. From patterned gait habits these muscle forces act to produce tensile limb loading during swing phase.
7. Braces with fixed ankle assemblies showed less weight relief than free ankle types. This may have been related to an unseating influence caused by the greater jolt effect felt during heel strike. Because of the prolonged heel strike period, full weight acceptance is borne on the heel instead of the whole foot as occured with free ankle assemblies.

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BIBLIOGRAPHY

American Academy of Orthopaedic Surgeons, Inc.: Orthopaedic Appliances Atlas J. W. Edwards Company, Ann Arbor, Michigan, Vol 1, 1952

Anderson, M L., Bray, J.: The UCLA functional long-leg brace. Clin. Orthop. *37*: 98, 1964.

Appoldt, F., Bennett, L.: A preliminary report on dynamic socket pressures Pressure and Force Measurement A report of a workshop sponsored by the Committee on Prosthetic Research and Development of The Division of Engineering, National Research Council, National Academy of Sciences, Washington, D C, 1968

Braces, Splints and Assistive Devices, an annotated bibliography, Committee on Prosthetic Orthotic Education, Division of Medical Sciences, National Academy of Sciences, National Research Council, Washington, D C., 1969.

Cochran, G: The clinical measurement and control of corrective and supportive forces. Clin. Orthop *59*. 209, 1971

Desai, S, Henderson, W. Engineering design of an orthopaedic brace. Berkeley and San Francisco, Biomechanics Laboratory of The University of California, 1961.

Eberhart H, Inman, V, Saunders, M, Levans, A., Bresler, B, Mc Cowan, T.: Fundamental studies of human locomotion and other information relating to design of artificial limbs. Report to National Research Council University of California, Berkeley, 1947.

Engen, T Research developements of lower extremity orthotic systems for patients with various functional deficits Texas Institute For Rehabilitation and Research, Houston, 1970.

Frankel, V, Burstein, A Statics and dynamics of joint loading. J Bone Joint Surg. *52-A*: 1255, 1970

Glimcher, M Lower limb orthopedic brace research. Thesis, Massachusetts Institute of Technology and the Harvard Medical School, Department of Orthopaedic Surgery at the Massachusetts General Hospital, 1950

Glimcher, M, Radin, E, Emrich, C The design of a new style ischial weight-bearing brace for use in the treatment of Legg-Perthes Disease Orthotics and Prosthetics *24* II, 1970.

Grynbaum, B, Sokolow, J, Lehneis, R Adjustable ischial weight-bearing brace: preliminary report Arch Phys Med *51* 460, 1969

Henderson, W., Lamoreux, L The orthotic prescription derived from a concept of basic orthotic functions Bull Pros. Res *BPR 10–11* 89, 1969

Hetenyi, M Handbook of experimental stress analysis J Wiley & Sons, New York, 1963

Hodge, J Outer fiber stresses in long leg brace under static load. Technical report 6705, U S. Army Medical Biomechanical Research Laboratory, Walter Reed Army Medical Center, Washington, D C, 1967

Inman, V. Conservation of energy in ambulation. Bull Pros Res. *BPR10-9* 26, 1968

Kirkpatrick, G, Day, E., Lehmann, J. Investigation of the performance of an ischial load-bearing leg brace. Experimental Mechanics 9 31, 1969

Lichlitner, M. D. Lower extremity bracing, problems and principles. Texas State J. Med. *62* 42, 1966.

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9. Axial loading of the medial upright was increased up to 7 times greater than the lateral upright when walking in slight abduction. The design implications are that when this gait pattern is present, the use of a lighter lateral upright or a stronger single medial upright may be possible.

10. The best rotational stability within the mid thigh-shell area was achieved when applied torsional moments were exerted proximally. From a comparison of the torsional moments in different combinations, this condition was optimized with a closed seat shell and patten bottom brace. Thus when optimal torsional stability is required a long-leg brace with ischial weight-bearing features is desirable.

11. Anterior-posterior and medial-lateral moments computed for the corset and seat shell rings were compared and considered. Their relevance to dynamic fracture stabilization is discussed.

12. Different rotational alignments of the ankle stirrup assemblies produced no distinguishing force patterns. The calf band loading trends recorded for different fixed ankle positions varied between anterior forces up to 2 kp for the plantar flexed position to posterior forces up to 2 kp for the dorsiflexed position. The fixed neutral ankle cycled between these ranges. Patten bottom, free and heel hinge assemblies produced higher forces ranging between 7 kp of posterior force for a patten bottom to 10 kp of anterior force with a caliper heel. These larger values are attributed to the less restricted walking patterns and the magnifying effect ankle motion produces on hinge malalignment.

13. A foot-position floor contact switch is described which synchronizes force maximum timing and foot positions with separate recorders by marking the analogs simultaneously.

BIBLIOGRAPHY

American Academy of Orthopaedic Surgeons, Inc.: Orthopaedic Appliances Atlas. J. W. Edwards Company, Ann Arbor, Michigan, Vol. 1, 1952.

ANDERSON, M. L., BRAY, J.: The UCLA functional long-leg brace. Clin. Orthop. *37*, 98, 1964.

APPOLDT, F., BENNETT, L.: A preliminary report on dynamic socket pressures. Pressure and Force Measurement. A report of a workshop sponsored by the Committee on Prosthetic Research and Development of The Division of Engineering, National Research Council, National Academy of Sciences, Washington, D.C., 1968.

BRACES, SPLINTS and Assistive Devices, an annotated bibliography, Committee on Prosthetic Orthotic Education, Division of Medical Sciences, National Academy of Sciences, National Research Council, Washington, D.C., 1969.

COCHRAN, G.: The clinical measurement and control of corrective and supportive forces. Clin. Orthop. *59*: 209, 1971.

DESAI, S., HENDERSON, W.: Engineering design of an orthopaedic brace. Berkeley and San Francisco, Biomechanics Laboratory of The University of California, 1961.

EBERHART, H., INMAN, V., SAUNDERS, M., LEVANS, A., BRESLER, B., MC COWAN, T.: Fundamental studies of human locomotion and other information relating to design of artificial limbs. Report to National Research Council. University of California, Berkeley, 1947.

ENGEN, T.: Research developements of lower extremity orthotic systems for patients with various functional deficits. Texas Institute For Rehabilitation and Research, Houston, 1970.

FRANKEL, V., BURSTEIN, A.: Statics and dynamics of joint loading. J. Bone Joint Surg. *52-A*: 1255, 1970.

GLIMCHER, M.: Lower limb orthopedic brace research. Thesis, Massachusetts Institute of Technology and the Harvard Medical School, Department of Orthopaedic Surgery at the Massachusetts General Hospital, 1950.

GLIMCHER, M., RADIN, E., EMRICH, C.: The design of a new style ischial weight-bearing brace for use in the treatment of Legg-Perthes Disease. Orthotics and Prosthetics *24*: 11, 1970.

GRYNBAUM, B., SOKOLOW, J., LEHNEIS, R.: Adjustable ischial weight-bearing brace: preliminary report. Arch. Phys. Med. *51*: 460, 1969.

HENDERSON, W., LAMOREUX, L.: The orthotic prescription derived from a concept of basic orthotic functions. Bull. Pros. Res. *BPR 10—11*: 89, 1969.

HETENYI, M.: Handbook of experimental stress analysis. J. Wiley & Sons, New York, 1963.

HODGE, J.: Outer fiber stresses in long leg brace under static load. Technical report 6705, U.S. Army Medical Biomechanical Research Laboratory, Walter Reed Army Medical Center, Washington, D.C., 1967.

INMAN, V.: Conservation of energy in ambulation. Bull. Pros. Res. *BPR10-9*: 26, 1968.

KIRKPATRICK, G., DAY, E., LEHMANN, J.: Investigation of the performance of an ischial load-bearing leg brace. Experimental Mechanics *9*: 31, 1969.

LECHLITNER, M. D.: Lower extremity bracing, problems and principles. Texas State J. Med. *62*, 42, 1966.

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STROHM, B., BRAY, J., COLACHIS, S.: Check-out evaluation and clinical experience of the UCLA functional long leg brace. Phys. Ther. *46*: 829, 1966.
VIEL, E.: Critique of lower extremity bracing. Orth. & Pros. 22, 38, 1968.
VON WERSSOWETZ, O.: Basic principles of lower extremity bracing. Amer. J. Phys. Med. *41*: 156, 1962.
WERNER, J.: Bracing of a complicated delayed union femoral shaft fracture. Phys. Ther. *49*: 1095, 1969.
WILSON, B.: Prosthetic and orthotics research in the United States. Rehabilitation Literature 24 98, 1963.

LEHMANN, J., DELATEUR, B., WARREN, G., SIMONS, B., GUY, A.: Biomechanical evaluation of braces for paraplegics. Arch. Phys. Med. *50*: 179, 1969.

LEHMANN, J., DELATEUR, B., WARREN, G., SIMONS, B.: Trends in lower extremity bracing. Arch. Phys. Med. *51*: 338, 1969.

LEHMANN, J., WARREN, G., DELATEUR, B., SIMONS, B., KIRKPATRICK, G.: Biomechanical evaluation of axial loading in ischial weight-bearing braces of various designs. Arch. Phys. Med. *51*: 331, 1969.

LEHMANN, J., WARREN, G., DELATEUR, B.: A biomechanical evaluation of knee stability in below knee braces. Arch. Phys. Med. *51*: 688, 1970.

LEHNEIS, H.: New concepts in lower extremity orthotics. Med. Clin. N. Amer. *53*: 585, 1969.

MAGORA, A., ROBIN, G., ADLER, E., LIBAI, A., EITAN, A.: Dynamic strain analysis of below-knee orthopedic braces. Amer. J. Phys. Med. *47*: 31, 1968.

MCCOLLOUGH, N., FRYER, C., GLANCY, J.: New Approach to patient analysis for orthotic prescription, part 1, the lower extremity. Art. Limbs. *14*: 68, 1970.

MOONEY, V., HARVEY, J.: *Application of lower extremity orthotics to weight-bearing relief.* Project number: Rd2580 MPO 68 CI. Division of Research and Demonstration Grants. Department of Health Education, and Welfare. Social and Rehabilitation Service. Washington, D.C., 1970.

MOONEY, V., NICHOL, V., HARVEY, P., SNELSON, R.: Cast-brace treatment for fractures of the distal part of the femur. J. Bone Jt. Surg. *52-A*: 1563, 1970

MURDOCH, G.: Prosthetic and orthotic practice. Edward Arnold, Ltd., Glasgow, 1970.

PERRY, J.: The mechanics of walking. Phys. Ther. *47*: 778, 1967.

Prosthetic and Orthotics. A report of a conference sponsored by the Committee on Prosthetics Research and Development, Division of Engineering, National Research Council, Washington, 1967.

Rehabilitation Engineering. Committee on Prosthetics Research and Development, National Academy of Sciences, Washington, D.C., 1971.

Report of The Fifth Workshop Panel on Lower Extremity Orthotics. Subcommittee on Design and Development. Committee on Prosthetics Research and Development, National Academy of Sciences, National Research Council, Washington, April 1968.

Report of Seventh Workshop Panel on Lower Extremity Orthotics of the Subcommittee on Design and Development, Committee on Prosthetics Research and Development, Division of Engineering, National Research Council, National Academy of Sciences, National Academy of Engineering, Downey, California, 1970.

ROBIN, G., MAGORA, A., ADLER, E., SALTIEL, J.: *Dynamic stress analysis of below-knee drop* foot braces. Med. & Biol. Engng *6*: 533, 1968.

RUSSEK, A., ESCHEN, F.: Ischial weight-bearing brace with a quadrilateral wood top. Orthop. Pros. Appl. J. *12*: 31, 1958.

RYDELL, N.: Forces acting on the femoral head prosthesis. Thesis. Tryckeri AB Litotyp, Goteborg, 1966.

SCHENCK, T., SOMERSET, J., PORTER, R: Stresses in orthopedic walking casts. Amer Soc Mech. Eng. *69-BHF-14*, 1969.

STAROS, A., PEIZER, E. Application of the Veterans Administration Prosthetics Center below-knee, weight-bearing brace to a bilateral case. Artif. Limbs. *9*: 35, 1965

STAROS, A.: Functional classification of lower extremity orthotics. Prosthetics International *3*, 1, 1971.

STAROS, A.: Modular design in orthotics Advances in orthotics, meeting Dundee, 1971.

STROHM, B., BRAY, J., COLACHIS, S.: The UCLA functional long leg brace: biomechanics and fabrication. J. Amer. Phys Ther. Ass. *43*: 713, 1963.

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An experimental study in dogs with an avascular, diaphyseal, intermediate fragment

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INTRODUCTION

The term « Soudure autogène », introduced by Danis in 1949, has been used to characterize the roentgenological healing pattern in compression osteosynthesis with a plate or screws and implies that a fracture gap is gradually eliminated during the healing phase. This type of fracture healing, at which the AO group aims, goes under the name « primary bone healing » (Müller et al. 1961). Characteristic of this healing process is considered to be the absence of roentgenologically visible periosteal callus, which means that the compression osteosynthesis gives satisfactory stability. Provided that the medullary circulation is intact, the development of callus obviusly shows an inverse relationship to the degree of stability (Yamagishi & Yoshimura 1955, Andersson 1965), and periosteal callus in compression osteosynthesis would thus seem to be a sign of disturbed healing (Wieser & Allgower 1962). The compression as such probably only means increased stability, while the healing rate is hardly accelerated. Geiser (1963) and Charnley (1965) claim that increased periosteal destruction during the operative procedure can be a cause of reduced callus development. In experiments on the sheep radius, Shenk & Willenegger (1963) showed that regenerating osteones pass over an osteotomy line. These authors consider that this form of healing, which with its secondary osteone formation resembles the rebuilding of normal cortical bone is worth striving for. They consider that under stable conditions the devitalized marginal layer of the cortex would induce regeneration of the Haversian systems (Shenk & Willenegger 1967). Geiser (1963) claims, however, on the basis of studies on rabbits, that all bone healing arises from periosteum and endosteum. This bone formation primarily fills out the fracture gap, while at the same time there is creeping substitution of the necrotic marginal layer. On the basis of

microangiographic and fluorescence microscopic studies in compression osteosynthesis on the dog tibia, Olerud & Danckwardt-Lillieström (1968) consider that new bone is formed mainly from blood vessels arising fom the medullary cavity and periosteum, but that at the same time, under certain conditions, intracanalicular bone formation is possible.

Thus, opinion on the importance of the different healing courses are somewhat divergent. By introducing an avasculai intermediate fragment into the compression zone, we have found it possible to study more closely the way in which the revascularization of an « extended » marginal zone takes place and the source of the main vascular supply. With the microangiographic technique used especially by Göthman (1960), Rhinelander (1962, 1968) has studies the revascularization of diaphyseal fractures. He has pointed out that the healing area in non-dislocated fractures obtains its essential vascular supply from the medullary cavity.

The aim of the present study was to elucidate the healing course on the incorporation of a completely devascularized, diaphyseal intermediate fragment, comprising the whole circumference of the diaphysis in a compression osteosynthesis with a plate.

METHOD

The study was performed on adult, mongrel dogs.

From an incision immediately lateral to the anterior tibial margin, the medial facet of the tibia was dissected free subperiosteally. A 6-hole AO plate was placed in position and fixed with screws through the 3 distal holes. The upper part of the plate was anchored with the compression instrument developed by AO. The fitting of the compression plate before the osteotomy was of great importance for the subsequent osteosynthesis. The plate was bent to that the osteotomy gaps of the fibular side should be compressed slightly before the gaps of the medial side. When the plate had been removed after the fitting, a *double osteotomy* was performed with a Gigli saw, corresponding to the area between the middle holes of the plate. The intermediate fragment was made somewhat broader againts the plate side. The ring-shaped intermediate

fragment then obtained was lifted out of its bed and was thereby completely freed from vascular communications. The osteotomy surfaces were smoothed with a file until they were quite even, after which they were washed with physiological NaCl solution. The intermediate fragment was replaced in its position and the AO plate was secured in place. After fine adjustment of the fractures to an exact position, the compression was performed. On compression, the intermediate frag-

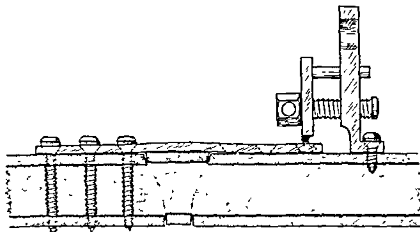


FIG 1 · Diagram of the experimental arrangements On compression, the fibular side is first adapted, on further compression the plate is straightened and the plate side is brought under compression The intermediate fragment is pressed down into its bed when the inner screws in the right and left main fragment finally are tightened.

ment, owing to its shape, was pressed firmly between the main fragments and the plate, so that the internal fixation was maximally stable. The part of the fibula between the levels of the osteotomy was resected, so that a continuity defect was produced at this site. The main incision was closed with single intracutaneous nylon sutures. The operation area was drained for 24 hours with a Kofferdam strip. The experimental set-up is presented schematically in Fig. 1.

All operations were performed on both tibiae, as a rule with an interval of 4-6 weeks In order to label the newly formed bone, the dogs were given two injections of Terramycin® (Pfizer)

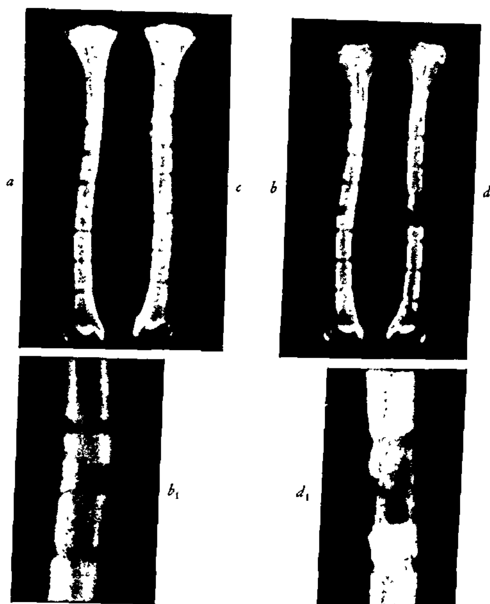


FIG. 2 - Roentgenograms showing the position of the intermediate fragment in the tibial diaphysis and the healing of the osteotomies: *a* - After an observation time of 4 weeks: The osteotomy gaps are still well visible but endosteal callus is present, especially in level with the lower gap. *b* - After an observation time of 6 weeks. The lower osteotomy gap is almost completely filled, and the upper gap is partially open. The fibular part of the intermediate fragment is undergoing pronounced reconstruction. *c* - After an observation time of 8 weeks. The lower osteotomy gap shows a tendency to delayed union, and the upper gap is almost filled. *The structure and mineral content of the intermediate fragment are essentially retained.* *d* - After an observation time of 10 weeks: Both osteotomy *gaps healed. Considerable reconstruction of the intermediate fragment and* especially the marginal zone of the upper main fragment. b_1 - enlargement of the 6 week preparation. d_1 - enlargement of the 10 week preparation.

These were given intraperitoneally (50 mg/kg body weight), one of them 1-2 weeks after the second operation and the other 2 days before the end of the experiment. The experiment was arranged so that specimens were obtained during the healing process at 4 weeks and up to 14 weeks, at intervals of 1-2 weeks.

At the end of the experiment the dogs were again anaesthetized. After primary heparınization (500 U Vitrum/kg), a catheter with an internal diameter of 1.5 mm was introduced into the carotid artery in the direction towards the heart. Through this catheter an Indian ink mixture (200 ml Günther Wagner Pelikan Indian ink in 800 ml isotonic NaCl» was infused with an ordinary Record syringe, at the beginning with excess pressure. After infusion of about 100-200 ml the animal usually died, after which the infusion was continued slowly for a further few hours until 5 litres of Indian ink mixture had been given from a height 120 cm above heart level. During the period of the infusion the dogs were kept in an upright position so that the Indian ink solution should gradually sediment in as many vessel branches as possible in the freely dependent limbs

After the Indian ink filling procedure the extremities were amputated at the knee joint and fixed in 96% alcohol which was changed daily or on every alternate day for 14 days. The soft tissues were cut away except on the area nearest to the osteotomy. The osteosynthesis plate was removed, and the specimens were photographed roentgenologically. The specimens were divided into two halves; one half was embedded in methyl methacrylate and the other was delcalcified for paraffin embedding

The paraffin embedded specimens were sawn into 1 mm thick sections, the paraffin was dissolved in xylol, and the sections were then placed in sodium benzoate and wintergreen oil according to the Spalteholz technique.

The plastic-embedded halves were sawn into ½ mm thick sections, parallel with the longitudinal axis of the bone, and were then ground down to a thickness of about 80-100 μ. These sections were studies microscopically with ultraviolett light with a filter combination suiting Terramycin fluorescence.

Some of the ground, plastic-embedded sections were photo-

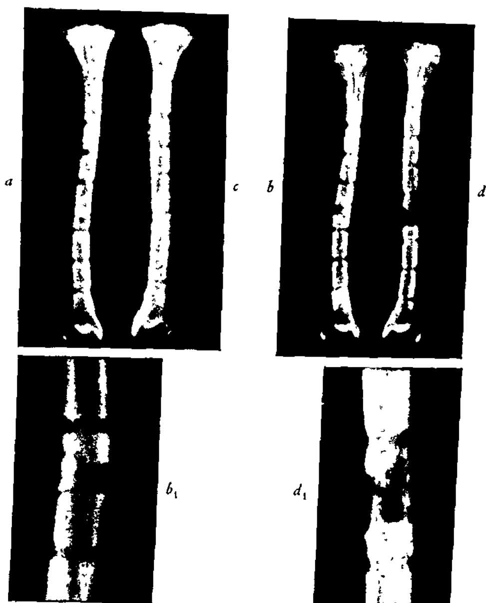


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the lower leg developed in these dogs. The remaining 6 dogs showed only moderate swelling 4 weeks after the operation and later. There were no infections. The roentgenograms showed a distinct osteotomy gap in the 4-weeks specimens (Fig. 2). These gaps were almost completely filled after an experimental period of 8 weeks, in accordance with Danis « Soudure autogène ». At 10 - 11 weeks the fracture gap could no longer be visualized roentgenologically (Fig. 3). In the 2 pseudarthrosis cases the upper gap had healed after 8 and 10 weeks, respectively.

On several roentgenograms a cloudy callus reaction a few mm high was observed on the medial side of the tibia. The intermediate fragment showed on some roentgenograms a considerable reduction of the calcium content in comparison with the main fragment (Fig. 2)



FIG 4 - Spalteholz specimen 4 weeks after osteotomy Microangiography shows that vascular communication has been established between the main fragments through the medullary cavity of the intermediate fragment A vein is here connecting the vascular systems of the two main fragments through the previous avascular intermediate fragment. More than the inner 2/3 of the cortex of the intermediate fragment is vascularized from the medullary cavity The intermediate fragment is surrounded by a thin periosteal vascular network, which is revascularizing the outer part of the cortex

graphed microroentgenologically for a study of the roentgenological microstructure, and examined in polarised light with respect to the course and orientation of the collagen fibrils.

Results

In spite of the mechanically rather unfavourable experimental arrangements, with double osteotomy, only about one week elapsed before the dogs bore weight on the affected limb when walking. There was some limp, however, for a period of up to 3 weeks in the dogs which healed without complications. In 2 of the 8 experiments pseudarthrosis occurred in the distal osteotomy, and pronunced swelling of

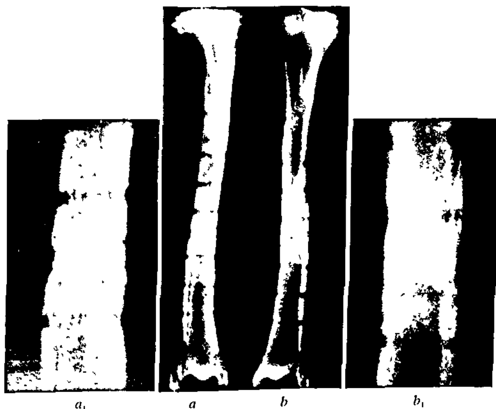


Fig. 3 - Roentgenograms showing the incorporation of the intermediate fragment after 7 (*a*) and 11 (*b*) weeks, respectively. a_1 - Partial enlargement after observation time of 7 weeks. The osteotomy gaps are almost completely filled: moderate endosteal callus. b_1 - Partial enlargement of roentgenogram at observation time of 11 weeks. The two osteotomy gaps are no longer visible. Decreased mineral content in the interemdiate fragment as a sign of reconstruction in progress. A tendency to spongious transformation within th distal main fragment.

both the plate side of the tibia and its lateral side. At the same time, in only exceptional cases were periosteal vessels (perhaps better expressed as vessels arising from the soft tissues, since the periosteum was largely destroyed) found to pass deeper into the cortex than some mm, i.e. 1/4 - 1/5 of the thickness of the cortex. This applied both to the plate side of tibia and its fibular side. Between the plate and the cortex a relatively richly vascular, fibrous soft tissue layer always extended (Fig. 7).

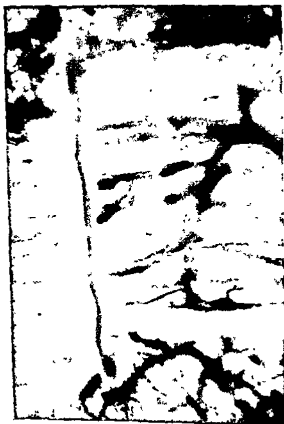


Fig. 6 Spalteholz specimen 6 weeks after osteotomy. Absolute bone contact between the fracture fragments at the fibular side. More than 4/5 of the cortex of the intermediate fragment is vascularized from the marrow canal. The osteotomy line is on the way to being crossed over by cutting heads from vessels in the intermediate fragment to the right (Partial enlargement of Fig 5)

ANGIOGRAPHIES

In specimens from experiments of the shortest period (4 weeks) the medullary circulation had become reestablished, with vascular communications crossing the two osteotomy lines (Fig. 4). With all probability, the well filled vessel constitutes an artery, and the broader vessel with less Indian ink density is probably a vein. Specimens from the 4th week also show that a large proportion of the primarily avascular fragment contained Indian ink filld vessels, the source of wich was almost solely the medullary cavity. Fig. 5 demonstrates besides a well vascularized medullary cavity also a vascular system wich extends from the medullary cavity almost to the outer layer of the cortex. This is found in Fig. 6, wich is an enlargement of Fig. 5. The type of vascularization is the same. This held for



FIG. 5 Spalteholz specimen 6 weeks after osteotomy The medullary cavity circulation is restored in the form of a relatively fine-meshed vascular network of the type seen in proliferative callus formation. Four-fifths of the fibular side cortex of the intermediate fragment is revascularized here from the medullary cavity Negligible periosteal revascularization, which is taking place during the formation of resorption cavities. Cartilage immediate outside the cortex between fibular fragment end (bottom to the right) and the intermediate fragment is undergoing enchondral ossification

both the plate side of the tibia and its lateral side. At the same time, in only exceptional cases were periosteal vessels (perhaps better expressed as vessels arising from the soft tissues, since the periosteum was largely destroyed) found to pass deeper into the cortex than some mm, i.e. 1/4 - 1/5 of the thickness of the cortex. This applied both to the plate side of tibia and its fibular side. Between the plate and the cortex a relatively richly vascular, fibrous soft tissue layer always extended (Fig. 7).



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An abundance of newly formed vessels were observed 4 weeks after the osteotomy in the fracture gap, where any form of space was present. The vessels originated mainly in the medullary cavity. It was often observed that medullary cavity vessels first entered the intermediate fragment or the main fragments and then passed further via Haversian canals to the fracture gap, there to connect with vessels with direct communication from the medullary cavity or from the periosteum (Fig. 8). When there was very close or absolute contact



FIG. 7 - *Spalteholz specimen 6 weeks after osteotomy.* In the upper part of the specimen there is an empty space, which represents the position of the metal plate. Numerous vessels in a fibrous layer are invading the area between the cortex and the plate. The periosteal vessels seem to be contributing very little to the vascular supply of the cortex.

between the fracture fragments, there was no space for vascular invasion. The vascular supply then developed mainly into canals leading from the medullary cavity, lying in the fragments close to the fracture line. Blood vessels passed into these canals, and made contact with vessels from the other side of the fracture gap (Fig. 8). This took place partly via so called cutting heads (Fig. 9), which drilled their canals possibly quite independently of previous canals in the bone.

In specimens 6-8 weeks after osteotomy, a considerable widening of the Haversian canal systems was found both in



FIG 8 - Spalteholz specimen 5 weeks after osteotomy. Osteotomy line on the plate side of the tibia (*top of the picture*) Vascular invasion from both the periosteal and the endosteal side The entire osteotomy line is vascularized Several vascular communications with the Haversian systems of both the intermediate and the main fragment



Fig. 9 - Spalteholz specimen 4 weeks after osteotomy. The fracture line, which otherwise is not vascularized, has been traversed by the vessels in a secondary osteone. The foregoing cutting head in the intermediate fragment can be seen to the left of the gap.

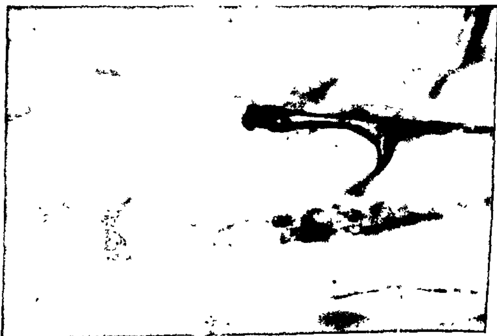


Fig. 10 - Spalteholz specimen 4 weeks after osteotomy. Cutting head with well-filled vessel loop is just about to traverse the fracture line

the main and in the intermediate fragment. Not seldom, several vessels were then observed in the same canal. As described above, these canals can be completely newly formed by so called cutter heads. In cases with several vessels in the same canal, one vessel was often found to be narrower than another, i.e. the former was probably an artery and the latter probably a vein.

The cutting head mechanism was also observed regularly into the fracture gap, from both the periosteal and endosteal side. On either side of the fracture line of a closely

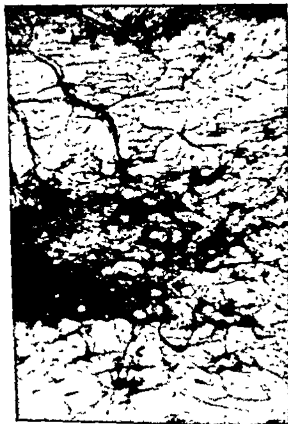


FIG. 11 - Spalteholz specimen 10 weeks after osteotomy. The intermediate fragment, which is seen to the left of the photograph, is penetrated by relatively wide vessels. The bone canals often contain more than one vessel. The vascular pattern in the medullary cavity indicates resorption of endosteal callus.

adapted fracture, a vessel loop was seen, wich worked its way forwards into the marginal zone. The mechanism was most clearly evident on fluorescence specimens, however (Fig. 19).

The fracture gap and its immediately surrounding area became more and more vascularized with time. After an observation time of 10 - 11 weeks the fracture gap itself was only just distinguishable - so evenly was the vascular pattern distributed within the intermediate and main fragments. Some specimens



FIG. 12 Spalteholz specimen 11 weeks after osteotomy. The osteotomy gap can be identified in relation to the divided fibula (in the lower part of the photograph) The cortical vessels in the osteotomy area are evenly distributed and show signs of maturity They are mainly orientated in the longitudinal direction of the cortex The intermediate fragment is to the right side of the photograph.

(Fig. 11) showed considerable absorption of cortical bone. Fig 12 gives a general picture of the angiographic pattern of an in-built intermediate fragment 11 weeks after the osteosynthesis. At this stage, direct vessels from the medullary cavity and periosteum to the fracture gap were seldom seen, so that these communications had probably re-formed even after this short time.

FLUORESCENCE MICROSCOPY - PERIOSTEAL REACTION

Four weeks after osteotomy, periosteal activity with newly formed bone was noted both over the main and the intermediate fragments. The bone formation was characterized by active tissue formation on the surface and resorption cavities in the deep areas immediately outside the original cortical bone (Fig. 13) At the level of the opening of the fracture gap new bone had developed in the form of almost fan-shaped trabecular bone (Fig. 14). On the fibular side, partly calcified cartilage had formed between the ends of the fibula and the intermediate fragment (Fig. 15).

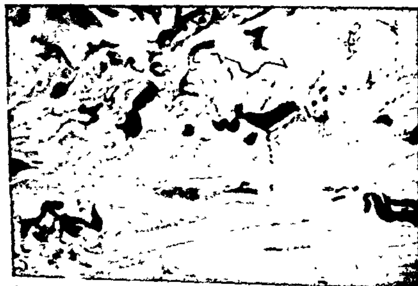


FIG. 13 Fluorescence specimen 4 weeks after osteotomy. Periosteal callus is seen with active tissue formation on the surface, and resorption cavities containing wide vessels in towards the cortex.

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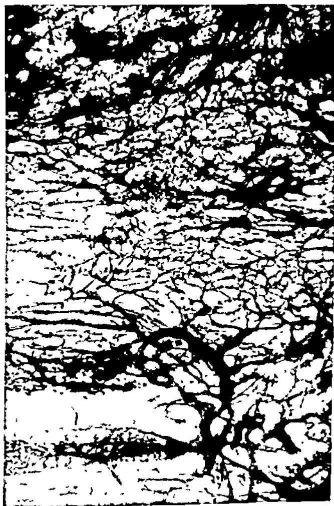


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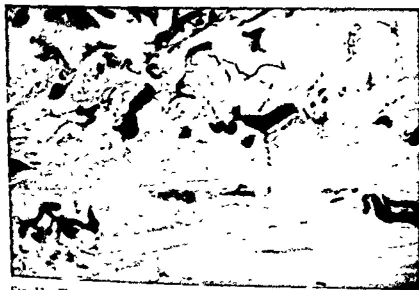


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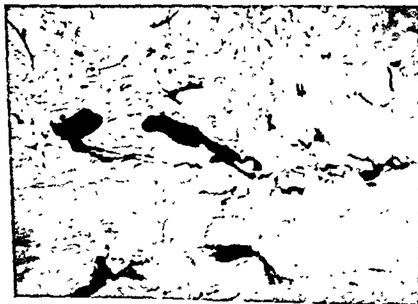
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FIG. 15 - Fluorescence specimen 5 weeks after osteotomy. *Intermediate fragment to the left.* There is resorption of the cortical corner on the periosteal side of both the intermediate and main fragment. Cartilage *tissue is observed above the intermediate fragment, and also trabecular* bone formation



Six weeks after osteotomy, patches of active bone formation were observed in the subperiosteal tissue. Fairly large resorption cavities were found in the primarly formed periosteal callus, and the periosteal superficial activity seemed to be considerable decreased, although the surface seemed to be still

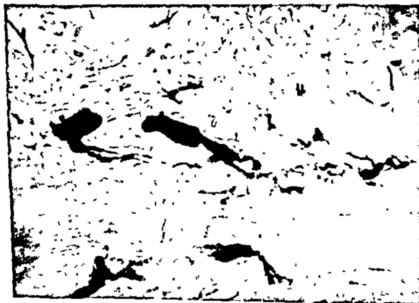


Fig 14 - Fluorescensc specimen 4 weeks after osteotomy. Trabecular bone under development is seen outside an osteotomy gap Active bone formation is in progress both periosteally and in towards the fracture gap.

Fig 16 - Fluorescence specimen 6 weeks after osteotomy Nearest to the cortex, a resorption cavity with wide vessels is being formed The callus outside this area is undergoing condensation while the peripheral surface of the cortex shows resorption First labelling 4 weeks after the osteotomy, second labelling 2 days before the end of the experiment



FIG 15 - Fluorescence specimen 5 weeks after osteotomy Intermediate fragment to the left There is resorption of the cortical corner on the periosteal side of both the intermediate and main fragment Cartilage tissue is observed above the intermediate fragment, and also trabecular bone formation



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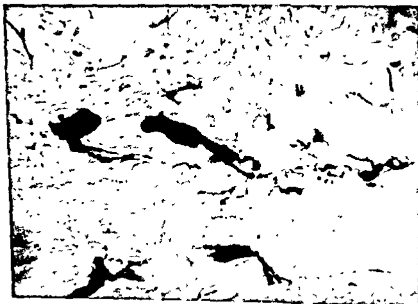


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ENDOSTEAL REACTION

Four weeks after osteotomy, active endosteal callus formation was seen, especially at the level of the fracture gaps. At a relatively short distance from the fractures gaps resorption areas were observed.

Five weeks after osteotomy there was still considerable activity at the level of the fracture gap, but it was more limited and concentrated. The resorption powers seemed to be clearly predominant (Fig. 18)

At an observation time of 6 weeks, the specimens showed practically only resorption in the medullary cavity, and 8 weeks after osteotomy the previously formed endosteal callus was almost completely resorbed. At later observation times endosteal bone formation activity was noted only exceptionally.



FIG 18 Fluorescence specimen 5 weeks after osteotomy Considerable activity within the endosteal callus at the level of the fracture line (visible in the lower middle part of the picture), although in *other places* resorption forces predominate

under construction. The second terramycin labelling 2 weeks after the first supported this observation (Fig. 16). The periosteal activity outside the fracture gap had decreased greatly in intensity, as indicated by the presence of resorption areas.

After an observation time of 8 weeks reconstruction of the periosteal callus and the subperiosteal bone had become more extensive, with a change-over to a new cortical structure (Fig. 17). Superficial activity within the periosteum was practically no longer observed, and this was also true at the level of the fracture gaps. Neither were any signs of active periosteal bone formation seen in specimens examined 10 weeks after the osteotomy. On the other hand, numerous resorption cavities were found within the area between the ends of the fibulae and the intermediate fragment, where endochondral bone formation was still observed.

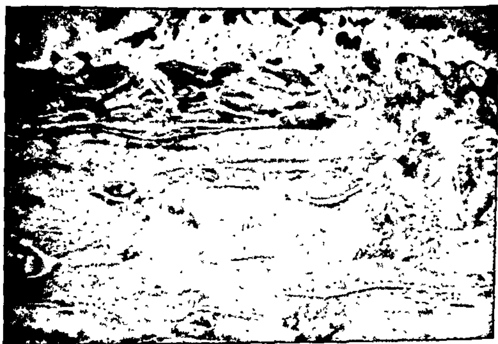


FIG. 17 - Fluorescence specimen 8 weeks after osteotomy. Reconstruction and condensation of the periosteal callus. The borderline between the cortex and periosteal callus has disappeared. The superficial activity is of a different character than that observed at shorter periods after the osteotomy The primary callus in the osteotomy gap is partially resorbed and penetrated by secondary osteones orientated in the longitudinal direction of the bone.

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At an observation time of 6 weeks, the specimens showed practically only resorption in the medullary cavity, and 8 weeks after osteotomy the previously formed endosteal callus was almost completely resorbed. At later observation times endosteal bone formation activity was noted only exceptionally.



FIG. 18 - Fluorescence specimen 5 weeks after osteotomy. Considerable activity within the endosteal callus at the level of the fracture line (visible in the lower middle part of the picture), although in other places resorption forces predominate

under construction. The second terramycin labelling 2 weeks after the first supported this observation (Fig. 16). The periosteal activity outside the fracture gap had decreased greatly in intensity, as indicated by the presence of resorption areas.

After an observation time of 8 weeks reconstruction of the periosteal callus and the subperiosteal bone had become more extensive, with a change-over to a new cortical structure (Fig. 17). Superficial activity within the periosteum was practically no longer observed, and this was also true at the level of the fracture gaps. Neither were any signs of active periosteal bone formation seen in specimens examined 10 weeks after the osteotomy. On the other hand, numerous resorption cavities were found within the area between the ends of the fibulae and the intermediate fragment, where endochondral bone formation was still observed.



FIG 17 - Fluorescence specimen 8 weeks after osteotomy. Reconstruction and condensation of the periosteal callus The borderline between the cortex and periosteal callus has disappeared. The superficial activity is of a different character than that observed at shorter periods after the osteotomy The primary callus in the osteotomy gap is partially resorbed and penetrated by secondary osteones orientated in the longitudinal direction of the bone

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FIG. 17 - Fluorescence specimen 8 weeks after osteotomy. Reconstruction and condensation of the periosteal callus. The borderline between the cortex and periosteal callus has disappeared. The superficial activity is of a different character than that observed at shorter periods after the osteotomy. Th[illegible] primary callus in the osteotomy gap is partially resorbed and penetrate[illegible] [illegible] secondary osteones orientated in the longitudinal direction of the [illegible]

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arches, one on either side of each osteotomy, had invaded the end of the fragments and eroded them (Fig. 19). Behind these eroding vessels (osteoclastic activity), bone was formed in the usual way (osteoblastic activity). The previously active resorptive forces were indicated by the formation of Howship's lacunae, which often filled rapidly with new bone, which formed a sharp borderline against the necrotic, avascular bone in the marginal zone.

Reconstruction zones with tetracycline labelling were found both in intermediate and main fragments. In dogs observed at



FIG. 20 Fluorescence specimen 6 weeks after osteotomy. Cutting head in the main fragment on the way towards the osteotomy gap during formation of a secondary osteone. The thin arteriolae divids into wide venous sinusoids.

4 weeks, on the right tibia only one labelling was observed in the intermediate fragment, and double-labelling in the main fragment was only seen at a distance of 1 cm and further from the osteotomy gap. At the time of the first labelling in this dog, i.e. 1 week after osteotomy on the right leg, no new bone formation was observed in the intermediate fragment or

in the area nearest to the fracture gap, but at that time there were probably already some functioning vessels.

In the specimens observed 4 weeks after osteotomy, Indian ink filled vessels were relatively numerous in the main fragment but considerably fewer in the intermediate fragment, which as yet showed only few resorption centres and isolated so called cutting heads (Fig. 20).

Five weeks after osteotomy, interfragmentary bone formation was seen to have taken place via vessels arising mainly from the medullary cavity but also from the periosteal side.



Fig. 21 - Fluorescence specimen 6 weeks after osteotomy. Centre of intermediate fragment. Double-labelled secondary osteones show that bone formation has occurred in the intermediate fragment as early as 2 weeks after the double osteotomy

These vessels often formed communications with vessels in Haversian canals on either side of the osteotomy gap. Double labelling was observed within one single osteone inside the intermediate fragment and very close to the fractura gap in the main fragment indicating, in accordance with the labelling of the specimens, that bone formation had occurred at these

sites after only 2 weeks following the osteotomy. Compared with the 4-week specimen, more numerous and larger resorption cavities were found (Fig. 21).

Six weeks after osteotomy, resorption cavities were seen within the bone primarly formed in the fracture gap (Fig. 22). The cavities also showed bone formation in the wall. A large number of vessels and osteones traversed the fracture gap (Fig. 23) In some areas where the fracture gap was not completely vascularized, the bone formation and bone resorption activities seemed to be completely ceased (Fig. 24), even



Fig. 22 Fluorescence specimen 6 weeks after osteotomy Resorption within the bone primarily formed in the fracture gap, through traversing secondary osteones

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FIG 24 Fluorescence specimen 5 weeks after osteotomy. The vascular invasion into the fracture gap, the resorption of the fragment ends and the subsequent bone formation have come to a stop before the entire fracture gap has become vascularized The vascularization has taken place from both endosteal and periosteal directions but has left the central part of the osteotomy gap undisturbed Deficient induction?

in front of vessels arising from the medullary cavity. The intermediate fragment showed an abundance of double-labelled osteones and many cutting heads (Fig. 25). The same held for the main fragments.

In specimens labelled at 5 and 10 weeks and observed at 10 weeks, considerable reconstruction of the bone in the fracture gap was seen, with numorous secondary osteones crossing the gap. In one of the specimens, direct contact was observed between the fragments, however, in a small area, with apparently arrested activity in the immediately surrounding region



FIG. 23 - Fluorescence specimen 6 weeks after osteotomy. Pronounced formation of secondary osteones crossing the fracture gap. *Within the upper part of the fracture gap the activity seems to be extinguished.*

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ments, with the possible exception of the tibial subperiosteal (compression side) area, were penetrated by relatively wide longitudinal canals with large Indian ink filled vessels. The walls of the canals were double-labelled almost throughout (Fig. 26).

At a yet longer period after the osteotomy, i.e. 11 weeks or more, the fracture gap became less and less distinct and the intermediate fragment increasingly reconstructed, so that

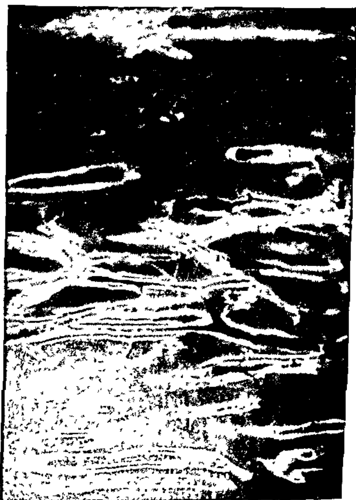


FIG 25 - Fluorescence specimen 8 weeks after osteotomy The main fracture ends are under active reconstruction by cutting heads The endosteal part of the cortex — the lower half of the photograph — shows double labelling as a sign of earlier rebuilding than in the upper part (the periosteal side of the cortex), where only single labellings are seen

the original structure of old bone was hardly distinguishable any longer.

In specimens observed 11 weeks and more after the osteotomy the structure of the fracture line could hardly be differentiated from that of the intermediate and main fragments.



FIG 26 - Fluorescence specimen 11 weeks after osteotomy Intermediate fragment with osteotomy gap in the lower right-hand part of the photograph A large number of wide resorption canals. A high percentage of the secondary osteones show double labelling Formation of new bone predominates

MICROROENTGENOLOGICAL STUDIES

These studies showed the occurrence of low mineralized newly formed bone in the fracture gap in specimens observed at 4 weeks after the osteotomy, but only, however, in gaps wide enough to be invaded by blood vessels (Fig. 27). After a longer period, i e 6-8 weeks, on the other hand, profuse interfragmentary bone formation was seen (Fig. 28). This was easily distinguishable from the original bone by its lower mineral content and by the fact that the osteocyte lacunae were somewhat larger and rounder than in older bone.

Eight weeks after osteotomy, there was resorption of bone previously formed in the fracture gap, which favoured reorientation of the bone in the longitudinal direction of the cortex. Several specimens showed, in this situation, a relatively small

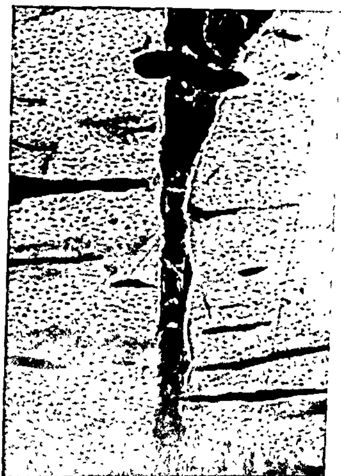


Fig. 27 Microroentgenogram 4 weeks after osteotomy. The osteotomy gap is filled with newly formed bone. Regenerating longitudinally directed osteones have just started to develop. Intermediate fragment to the left

amount of new bone formation in the large resorption cavities (Fig. 29).

Microroentgenography of specimens 10 weeks after osteotomy showed that a considerable area of old bone on either side of the osteotomy gap and within the intermediate fragment

seemed to have been replaced by new bone. The originally formed bone in the gap with its orientation in the direction along the fracture line was traversed by new osteones with a structure oriented longitudinal to the cortex (Fig. 30). Even on



Fig 28 - Microroentgenogram 6 weeks after osteotomy. Enlargement of Haversian canal systems occurs to a large extent, and osteone formation across the fracture gap is not yet observed, but on the other hand bone resorption is seen along the fracture gap, with subsequent bone formation The intermediate fragment is to the right

microroentgenograms of higher magnification at an observation time of 10 weeks, the fracture gaps could only be distinguished by the difference in structure between old and new bone. An abrupt ending of an osteone in the gap, i e. without a bow-

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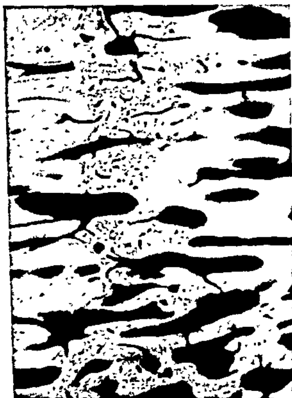


Fig. 31

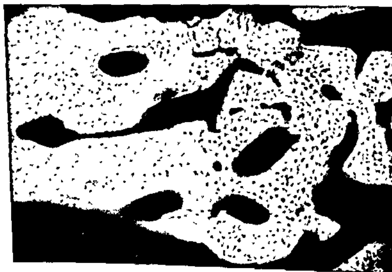




FIG. 29 - Microroentgenogram 8 weeks after osteotomy. Intermediate fragment to the left. Resorption cavities fairly evenly distributed within the marginal zone of both the intermediate and the main fragment. The bone primarily formed in the fracture gap is undergoing the same reconstruction as the surrounding cortical bone. Reorientation of the structure in the fracture gap is evident.

FIG 30 - Microroentgenogram 10 weeks after osteotomy. Intermediate fragment to the right. The osteotomy line in the main fragment is only just distinguishable. The structure of the newly formed bone in the fracture gap can be followed in form of osteone formations into the intermediate fragment, which still contains bone not yet rebuilt

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FIG 31 - Microroentgenogram of a detail of the marginal zone of the main fragment from a specimen 10 weeks after osteotomy The old osteotomy line can just be distinguished. The newly formed bone on the right of the photograph is in contact with well-developed newly formed osteones, which fill out the centre of the left half of the photograph The bone yet not rebuilt is easily distinguishable by its greater mineral density and by the shape and size of the osteocyte lacunae

large extent in the longitudinal direction of the osteotomy gap, with a few connections into the cortex on either side of the gap (Fig. 33). This held mainly for gaps in which direct angiogenic, i e. primary bone formation had occurred. In specimens observed 8 weeks after the osteotomy, newly formed secondary osteones were seen, which traversed the fracture gap and which had produced resorption cavities in the primary bone formed in the gap (Fig. 34). Collagen fibrils were found here to be partly oriented in the longitudinal direction of the cortex. The primary orientation of large parts of the collagen was seen to persist for a relatively long period, i.e. 10 weeks



FIG 33 - Polarisation photograph 5 weeks after osteotomy. The collagenous structures are mainly oriented along the osteotomy gap but have attachments here and there in the surrounding cortex. Intermediate fragment to the right and main fragment to the left.

and possibly even longer (Fig. 35) Several specimens exhibited numerous resorption cavities, especially within the intermediate fragment, an expression of active reconstruction and spongious transformation of the cortical bone due to decreased elasticity and a reduced demand for strength on the bone fixed by the

shaped Howship's attachment into a fragment, means a defective anchorage which would only be reliable if there was contact with the deeper located osteones (Fig. 31). In specimens observed 11 weeks after osteotomy, the original bone was only seen in patches around the osteotomy gap which in this case was not

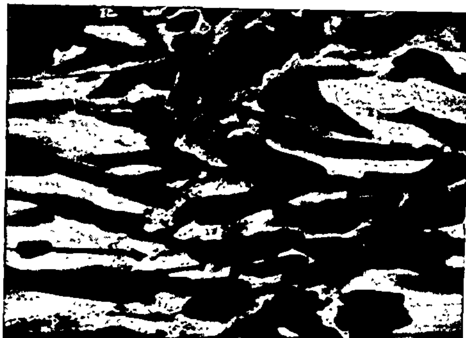


FIG 32 - Microroentgenogram from specimen 11 weeks after osteotomy. Intermediate fragment to the left. The old osteotomy line is just distinguishable immediately to the left of the midline. Reorientation of the bone newly formed in the fracture gap seems to be largely completed. The resorption is pronounced both in the intermediate fragment to the right and in the main fragment to the left. Bone from the time prior to the osteotomy is seen only in occasional patches. The bone is spongious in structure Compare fluorescence specimen in Fig 26

delimitable (Fig. 32). Both the fracture ends of the main fragments and the intermediate fragment itself thus exhibited considerable reconstruction, although this was still not completed within the total observation period of the experiment.

STUDIES IN POLARISED LIGHT

Examination of the specimens in polarised light showed that 6 weeks after the osteotomy the collagen *fibres ran to a*

compression plate. 10 - 12 weeks after the osteotomy a confusion of collagen fibres was seen within the ends of the fragments and within the bone formed in the fracture gap, but with a tendency, however, to orientation in the longitudinal direction of the cortex (Fig. 36). The fragment end was still apparent with some sharpness, however, indicating that the reconstruction was far from complete, in spite of the fact on macroroentgenograms the osteotomy gap showed complete bridging.



Fig 36 - Polarisation photograph from specimen 11 weeks after osteotomy Main fragment to the right, where the osteotomy gap is identified by bone which has not yet been rebuilt, easily seen at the level of the middle of the photograph The osteotomy gap itself is filled by relatively irregularly layered collagen fibres In the upper half of the photograph, to the left, there is a longitudinal orientation of rebuilt bone in the intermediate fragment

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Fig 35 Polarisation photograph from specimen 9 weeks after osteotomy The orientation of the collagenous structure in the fracture gap has been maintained, but reorientation is in progress



Fig. 34 - Polarisation photograph from specimen 8 weeks after osteotomy. The osteotomy gap is only slightly distinguishable. In the centre of the photograph, however, there is a well-developed collagenous formation passing from the right side of the main fragment to the left side of the intermediate fragment, straight through previously formed collagenous structures in the fracture gap.

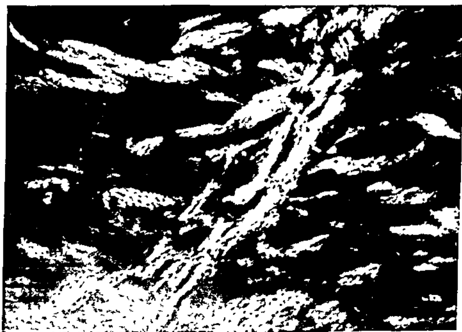


Fig 35

teal growth still occurred during the 4th - 6th week after a double osteotomy, an observation which was not made in the previously studied single osteotomy (Olerud & Danckwardt-Lilliestróm 1968). The periosteal growth took place rather slowly, however, and extensive resorption cavities developed in the bottom layer of the periosteal callus. Cartilage formation, as an expression of instability, occurred within the endosteum and on the compression plate side of the tibia only in cases of pseudarthrosis. On the other hand, cartilage formation was observed in all cases in the area between the fibular ends and the intermediate fragment. Thus there would seem to be more pronounced instability on the fibular side than on the plate sida of the tibia. Two factors contribute to this. As mentioned previously, a screw-attached compression plate hardly fixed any other region than that close to the plate. On weight-bearing with such an osteosynthesis, movements always occur, which become increasingly greater the further the distance from the fixation centre of the plate. Another reason for the cartilage formation on the lateral side of the tibia may be the movements produced by the osteotomixed but not fixed fibular ends.

The operative trauma in transverse osteotomy results not only in damage to the periosteal circulation but also to a cortical circulatory disturbance nearest to the osteotomy gap The normal intracortical vascular supply arises mainly from the medullary cavity, and to the extent that screws cause damage to the medullary blood flow, a disturbance of the intracortical circulation occurs, with subsequent enlargement of the so called avascular marginal zone. This is certainly a factor of importance in bones with a small marrow canal. In several types of fracture, however, intracortical vascular damage is probably considerably greater because of extensive periosteal and endosteal destruction of blood vessels, caused by local thrombosis and possibly also fat embolisation

The revascularization pattern in the enlarged, cortical avascular area which an avascular intermediate fragment comprises, does not differ from the revascularization system in single osteotomy The medullary circulation would seem to play the largest role, since almost 4/5 of the cortex is revascularized from the endosteum. This also holds for the lateral side of the tibia, the periosteal circulation of wich is not disturbed by

Discussion

The degree of stability is an essential factor for fracture healing. In the present investigation the prerequisites for satisfactory stability were fewer than in compression osteosynthesis of a simple, transverse osteotomy gap. This was indicated by the occurrence of pseudarthroses. A compression plate osteosynthesis will hardly give complete stability, since it is probably impossible to produce, by compression over the plate, exactly the same pressure conditions within the fracture gap on the compression plate side of a diaphysis as on the other side, which must obviously be a prerequisite for absolute stability. In the investigations by Shenk & Willenegger (1963) on the sheep radius, the stability was certainly favoured by the undisturbed ulna.

During the healing course, a roentgenologically just visible periosteal callus reaction was seen outside the double osteotomy lines. In our earlier study on compression osteosynthesis in simple osteotomy (Olerud & Danckwardt-Lillieström 1968), where the stability was probably considerably better, there was no roentgenologically visible periosteal callus reaction. The operative procedure in the two series were essentially similar and thus cannot explain the difference in callus reaction. For a certain period of time, however, it must be assumed that there will be a total elimination of the medullary circulation in the intermediate fragment, a circumstance which can have a contributory effect on the development of callus. The smaller degree of stability in the double osteotomy might also contribute to the increased periosteal surface activity.

Even after reaming the medullary cavity on ostetomized rabbit tibias, stabilized by nails, only small amount of periosteal bone was produced when the cortical damage was limited (Danckwardt-Lillieström, Lorenzi & Olerud 1970). In case of large cortical damage, because of intracortical fat embolization produced during reaming (Danckwardt-Lilliestròm 1969), the periosteal bone formation was extensive (Danckwardt-Lilliestrom et al. 1970).

The microscopic study of the fluorescence specimens showed an essentially increased periosteal activity in comparison with corresponding specimens with single osteotomy Thus, perios-

ment side or from the intermediate fragment side. They then form direct secondary osteones. The primary bone formation according to Shenk & Willenegger then seems to take place but requires ideal conditions.

A third variation of vascular invasion into avascular bone occurs within the osteotomy gap itself. Vessels bore their way into the avascular edges of the fragment ends on either side of the actual fragment contact and form Howship's lacunae. The angiographic pattern is very characteristic and uniform and is most closely reminiscent of a pair of tongs which grasp the fracture gap from both sides. In principle, this activity is perhaps not greatly different from that represented by cutting heads. Close on the heels of these vessel loops follows newly formed bone, which fills out the gap between the fracture ends. By means of vascular contact across the Haversian canal systems, intracortical attachment occurs. Resorption alone, or predominantly, within the fracture area is seen from time to time but is not a general finding. Neither does resorption of marginal zones, as suggested by Bohler, occur in the avascular fragment. The reconstruction of the avascular fragment ends and the avascular intermediate fragment takes place gradually via established vascular canals, so to speak from the inside, and via cutting heads. The avascular structures thereby retain their stability and function In this way new bone gradually takes over the functional stresses.

In those cases where space exist for endosteal and periosteal vascular invasion of the fracture gap, the gap often seems to be filled with bone after only 4 - 6 weeks This primary new bone has relatively poor attachment in the avascular bone ends until vascular communications are made with the Haversian systems in the main fragment. In any case the newly formed bone is primarily orientated along the direction of the fracture line Six to eight weeks after osteotomy, considerable resorption takes place within the bone newly formed in the fracture gap, to advantage of the formation of new secondary osteones, which cross over the fracture gap This osteone formation corresponds the direct osteone formation (intracanalicular bone formation) and also that osteone formation which takes place when newly formed vessels have to take a roundabout way over the cortical

the osteosynthesis material. The finding that the medullary circulation involves the greater part of the medial facet of the tibia is more easily explained, since the osteosynthesis material lies here in the way of periosteal revascularization. Peculiarly enough, however, the relatively abundant circulation in the fibrous layer surrounding the plate seemed not to have communication with the cortical circulation, either.

Bone canals from the medullary cavity widen both for widening old vessels and newly formed vessels, which bud further in towards the Haversian canal systems. Within the main fragments, contact is made with previously undamaged vascular systems on the one side, and new formed vessels on the other side. The outgrowth of vessels takes place up to the fracture gap, and to the extent that direct bone contact occurs here, communication is made with vessels arising from the fragment of the opposite side. If space allows, the osteotomy gap is also filled with newly formed vessels, mainly from the medullary cavity, which often make contact with the vessels growing from the Haversian canals. The primary vascular invasion is accompanied by bone resorption and bone formation both within the marginal zone of the main fragment and in the intermediate fragment.

The revascularization with the aid of the so called cutting heads is a process which, to judge by the number of cutting heads in the sections, seems to occur somewhat later than the primary revascularization. According to Shenk & Willenegger, such a cutting head erodes 50 - 80 μ per day, which means that 1 mm bone would be revascularized in 12 - 20 days. This revascularization process is thus very slow, and it must be asked whether it alone can be responsible for the total revascularization and bone reconstruction.

With a marginal zone of only 2 - 3 mm, and often it is considerably larger, blood vessels would hardly reach the fracture gap within the course of 6 weeks. By means of double labelling with Terramycin, we estimated the cortical avascularity in the end of the main fragment in this type of experiment to be about 8 mm.

The cutting heads followed by their vessel loops seem to be able, however, to traverse the fracture gap from the main frag-

Conclusions

Instability seems to be an *important factor in* the development of periosteal callus. With adequate stability, the callus undergoes regressive changes long before the fracture is healed. With relative stability *there* is *extended, though not* especially active, periosteal callus proliferation, while at the same time regressive changes can be observed.

The development of blood vessels within avascular areas in the fracture region is favoured by rigid fixation and followed by early filling of interfragmentary spaces with primary osteones or trabecular bone though *with relatively poor attachment to the* avascular, cortical bone. Under certain conditions, viz. absolute bone contact across the fracture gap, intracanalicular bone formation can occur with direct *formation of secondary osteones* crossing over the fracture line. This process is time-consuming and thus cannot be solely responsible for the bone healing. A practically *identical process with formation of cutting heads* is developed on either side of the fracture gap if this does not permit primary vascular invasion Reestablished circulation in already *existing Haversian canals may join the rebuilding by direct local* resorption and bone formation The microangiographic technique used shows extensive and relatively rapid revascularization *of the medullary cavity and of preformed cortical canals, where* vascular invasion from the periosteal side into avascular cortex seems to play a secondary role. Intracanalicular bone formation over the fracture gap is dependent, as regards *time, upon the* size of the avascular marginal zone, and therefore bone formation from the endosteal and periosteal direction can often predominate Primary osteones, i e. the new formed bone laid down in the longitudinal direction of the fracture gap and the trabecular bone laid down within the fracture defect, are rebuilt simultaneously with the formation of secondary *osteones* across any fracture gap. The reconstruction of the avascular *intermediate* fragment takes place, under the conditions of this experiment, approximately concomitantly with the reconstruction of the fracture gap. Roentgenologically the fracture gap seems to be bridged *after* an experimental period of 10 - 12 weeks, but examination of the bone structure by microroent-

fragment end in order to cross the fracture gap. Thus in cases of large avascular marginal zones the primary bone healing, acvording to Schenk & Willenegger, means a timeconsuming healing process.

The above mentioned resorption cavities appearing in the bone primarily laid down in the fracture gap, can in detail be seen on microroentgenograms, where the course can be followed clearly. It is striking, however, that the resoption often seems to predominante over the process of osteone formation; in those cases where this rebuilding can be determined, the newly formed bone in the longitudinal resoption canals seem to be fairly sparse. This is possibly an expression of much too little strain in a diaphyseal area wich is under the influence of a relatively inelastic metal plate. It would seem that a spongious transformation — the occurrence of a number of resorption cavities — of the cortex can develop if the bone is not subjected to the mechanical forces for which it is intended.

The number of newly formed secondary osteones which traverse the osteotomy gap will be decisive for the strength of the bone. The primarily formed bone in the fracture gap will have, in comparison with the secondary osteones, considerably weaker anchorage in the fracture ends, which will result in inadequate strength of the bone for a considerable length of time, despite the fact that roentgenologically the fracture is filled with bone. In this respect the polarisation studies complement particularly the microroentgenological studies. In polarised light, this experimental material relatively seldom showed collagen fibres with direct attachment on both sides of the osteotomy gap. This seemed to hold also for specimen from 10 - 12 weeks after the osteotomy, where despite a general longitudinal orientation the collagenous structures were still located relatively irregularly and as yet far from filling the entire cross section of the osteotomy.

The microroentgenological and polarisation studies thus indicated that a long period of reconstruction remained before the bone structure became normal. It may be asked whether normalization would, in fact, occur as long as the metal plate remained

Conclusions

Instability seems to be an important factor in the development of periosteal callus. With adequate stability, the callus undergoes regressive changes long before the fracture is healed. With relative stability there is extended, though not especially active, periosteal callus proliferation, while at the same time regressive changes can be observed.

The development of blood vessels within avascular areas in the fracture region is favoured by rigid fixation and followed by early filling of interfragmentary spaces with primary osteones or trabecular bone though with relatively poor attachment to the avascular, cortical bone. Under certain conditions, viz. absolute bone contact across the fracture gap, intracanalicular bone formation can occur with direct formation of secondary osteones crossing over the fracture line. This process is time-consuming and thus cannot be solely responsible for the bone healing. A practically identical process with formation of cutting heads is developed on either side of the fracture gap if this does not permit primary vascular invasion Reestablished circulation in already existing Haversian canals may join the rebuilding by direct local resorption and bone formation. The microangiographic technique used shows extensive and relatively rapid revascularization of the medullary cavity and of preformed cortical canals, where vascular invasion from the periosteal side into avascular cortex seems to play a secondary role Intracanalicular bone formation over the fracture gap is dependent, as regards time, upon the size of the avascular marginal zone, and therefore bone formation from the endosteal and periosteal direction can often predominate Primary osteones, i.e. the new formed bone laid down in the longitudinal direction of the fracture gap and the trabecular bone laid down within the fracture defect, are rebuilt simultaneously with the formation of secondary osteones across any fracture gap. The reconstruction of the avascular intermediate fragment takes place, under the conditions of this experiment, approximately concomitantly with the reconstruction of the fracture gap. Roentgenologically the fracture gap seems to be bridged after an experimental period of 10 - 12 weeks, but examination of the bone structure by microroent-

genography and in polarised light indicates that further rebuilding is required before a normal structure can be expected, if, in fact, normalization can be expected at all as long as the bone is fixed by a plate and screws.

Summary

The healing course of a fracture with a compression-fixed, avascular diaphyseal intermediate fragment comprising the whole circumference of the bone was studied by Indian ink microangiography, the Spalteholtz technique and labelling with Terramycin, among other methods. The two-levelled osteotomy was performed on dog tibias with a Gilgi saw. The osteosyntheses were produced by mean of compression over a metal plate according to AO.

1. Four-fifths of the revascularization of the intermediate fragment took place from regenerated medullary circulation. The marginal zones of the main fragments and the fracture gaps were revascularized in the same way.

2. Under the experimental conditions used, the intermediate fragment seemed within 2 weeks to be supplied primarily with some vessels through existing Haversian canal systems. In a secondary phase revascularization of the cortex took place via so called cutting heads.

3. As far as space allowed, the osteotomy gaps were invaded rapidly by newly formed vessels, which were followed, under stable conditions, by angiogenic bone formation.

4. Periosteal callus was developed both over the intermediate fragment and the main fragments. The extended period of proliferation of this callus indicated some instability in the compression system. Simultaneous with this proliferation, however, regressive changes occurred within the callus.

5. The intermediate fragment was rebuilt by simultaneous bone resorption and bone construction from the inside of the Haversian canal systems containing functioning vessels. A large part of the rebuilding process took place by means of cutting heads, which directly formed secondary osteones. The same process applied to the avascular marginal zone in the main frag-

ments and to the primarily formed bone in the fracture gap, in preparation for reorientation of the collagenous structures according to functional demands.

6. The osteotomy zones were rebuilt without any collapse and the intermediate fragment kept its size throughout the healing period.

7. Whether the endosteal-periosteal bone formation predominates over the intracanalicular bone formation in the gap would seem to depend upon the size of the avascular zones. Regeneration of secondary osteones with cutting heads is a slow rebuilding process and is therefore easily surpassed by endosteal and periosteal new bone formation if prerequisites for such bone formation exist.

8 An osteosynthesis plate gives the bone essential support, which can contribute to early regressive changes on reconstruction of callus and cortical bone. The bone will thus become adapted to functional demands, which is evident in the occurence of an increased number of resorption cavities and big canals. This gives so called spongious transformation of the cortical bone.

BIBLIOGRAPHY

ANDERSON L D *Compression Plate Fixation and the Effect of Different Types of Internal Fixation on Fracture Healing* Journal of Bone and Joint Surgery 47/A 191, 1965

CHARNLEY J *Die konservative Therapie der Extremitätenfrakturen* Springer Verlag, Berlin-Heidelberg New York, 1968

DANCKWARDT-LILLIESTRÖM G *Reaming of the Medullary Cavity and Its Effect on Diaphyseal Bone* Acta Orthop Scand Suppl *128*, 1969

DANCKWARDT LILLIESTRÖM G, LORENZI G L & OLERUD S: *Intramedullary nailing after Reaming* Acta Orthop Scand Suppl *134*, 1970

DANIS R *Théorie et pratique de l'Ostéosynthèse.* Masson & Cie, Paris, 1949

GEISER M *Beitrage zur Biologie der Frakturheilung* Enke-Verlag, 1963.

GÖTHMAN L *The Normal Arterial Pattern of the Rabbit Tibia* A Microangiographic Study. Acta Chir. Scand, *120*, 201, 1960

MÜLLER M E, ALLGÖWER M and WILLENEGGER H · *Technique of Internal Fixation of Fractures* Springer-Verlag, Berlin-Heidelberg-New York, 1965

OLERUD S, and DANCKWARDT LILLIESTRÖM G. *Fracture Healing in Compression Osteosynthesis in the Dog* Journal of Bone and Joint Surgery *50/B* 844-851, Nov, 1968

RHINELANDER F. W. and BARAGRY R. A.: *Microangiography in Bone Healing* I. Undisplaced Closed Fractures. Journal of Bone and Joint Surgery *44/A*: 1273-1298, Oct., 1962.

RHINELANDER F. W.: *The Normal Microcirculation of Diaphyseal Cortex and Its Response to Fracture.* Journal of Bone and Joint Surgery *50/A*: 784-800, June, 1968.

SCHENK R. and WILLENEGGER H.: *Zum histologischen Bild der sogenannten Primärheilung der Knochenkompakta nach experimentellen Osteotomien am Hund.* Experientia *19*, 593, 1963.

SCHENK R. and WILLENEGGER H.: *Zur Histologie der primären Knochenheilung.* Langenbecks Archiv für klinische Chirurgie *308*, 440, 1964.

SCHENK R. and WILLENEGGER H.: *Morphological Findings in Primary Fractur Healing.* Callus Formation Symposium on the Biology of Fracture Healing, Budapest. Symp. Biol. Hung. *7*, 75, 1967.

WIESER C. and ALLGOWER M.: *La Significance du cal dans la stabilité des ostéosyntheses.* Med. et Hyg. (Genève) *20*, 745, 1962.

YAMAGISHI M. and YOSHIMURA Y.: *Biomechanics of Fracture Healing.* Journal of Bone and Joint Surgery *37/A*, 1035, 1955.

VITAMIN D AND SKELETAL METABOLISM

EXPERIMENTAL STUDIES IN THE RAT

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CONTENTS

FOREWORD

There are few topics in medicine, that have attracted the interest of so many investigators as the physiological significance(s) of Vitamin D. However, in spite of extensive research and innumerable publications, knowledge concerning the mode of action of the vitamin on the calcium homeostasis of the body is still incomplete.

The complexity of the "simple question" how does vitamin D influence skeletal metabolism? defies a simple experimental solution and requires an integrated, multilevel approach. With this in mind the authors have during the last years tried to throw some light on the question by conducting a correlated series of experimental investigations. The study started in Chicago, Illinois, was continued in the Orthopaedic Research Laboratory in Uppsala and later in Umeå, Sweden. The results were discussed at each stage by the senior authors (J. A. S. and R. D. R.) and each step was planned in close collaboration.

The results of these studies reinforce certain previous findings under standard conditions not prevalent in the multitude of separate studies in separate laboratories by separate people in the past, and add new aspects on the mechanism of action of vitamin D on bone.

The publication of the different sections of the work in the form of a supplementum was chosen since it gives a more coherent survey of the results obtained.

The investigations were aided by grants from the U. S. Atomic Energy Commission, AT (11—1) 1601, the United States Public Health Service (N. I. H. 47153) and the Swedish Medical Research Council, which are gratefluly acknowledged. The printing costs of this publication have been financed partially by a grant from the Swedish Medical Research Council (contract B 69-50 T-2954-01).

INTRODUCTION

Rickets as a clinical entity was first reported in 1645 in a thesis by Whistler[1]) entitled "De morbo puerili Anglorum quem patrio idiomate indigenae vocant, The Rickets". A detailed description of the disease followed 5 years later by Glison (1650). Almost two centuries later Guerin (1838) was probably the first to produce rickets in puppies and suggested that rickets resulted from a faulty diet. The curative effect of cod liver oil in clinical rickets was pointed out by Trousseau (1865). Hopkins in 1912 first suggested that rickets was due to a dietary deficiency and the same year Funk (1912) propounded the "vitamin hypothesis" according to which the existence of separate anti-beriberi, anti-scurvy, anti-rachitic and anti-pellagra "vitamins" was postulated. Huldschinsky (1919) showed that rickets could be cured by artificial light no less than by direct sunlight. Steenbock and his co-workers, in 1924, deduced that ultraviolet rays activated some vitamin precursors in the skin of the body or in the food. Hess and Weinstock (1924) confirmed this shortly afterwards. One year later a crude cholesterol fraction was isolated from cod-liver-oil, by the same authors, and it was thought to be the "anti-rachitic provitamin". The vitamin itself was isolated, in a pure state, from the irradiation products of ergosterol by Askew et al. in 1930 and by Windhaus et al. in 1932. The vitamin was first named vitamin D or calciferol. Ergocalciferol was later adopted as its official name. Two calcemic sterols have been prepared in crystalline form, namely vitamin D_2 or dihydrotachysterol-2 and vitamin D_3 or dihydrotachysterol-3, the latter showing a much higher effect in intenstinal calcium absorption than the former. Excellent reviews on the mode of action of vitamin D are to be found in the literature (Nicolaysen and Eeg-Larsen 1953, Harris 1956, Weinmann and Sicher 1957, Firschein 1963, Frederich 1965, Harrison 1965/66, DeLuca 1967, 1969, Forbes 1967, Fourman et al. 1968, Norman 1968).

[1]) A reference list to this part of the work is to be found on page 82.

Vitamin D-deficiency in humans is a pathologic condition of early childhood. It is characterized clinically by decreased body growth, especially of the length of the long bones, softening of the bones of the skull (craniotobes), swelling of the costosternal synchondroses (rosary) as well as the metaphyseal parts of the long bones and radiologically by widening of the growth cartilage of the long bones with cup-shaped and irregular metaphyses. Blood chemistry is usually changed and is characterized by low levels of the serum phosphate and sometimes the serum calcium. The histological changes include increase in breath of the zone of provisional calcification, inadequate mineralization of the newly formed bone matrix and appearance of osteoid tissue in the metaphyseal area. Renal disease and several other metabolic disturbances of totally different etiologies can give rise to a clinical picture resembling rickets.

By varying the amount of calcium and phosphate and depriving the diet of vitamin D a condition morphologically similar to that of human dietary rickets has been induced in experimental animals, providing the opportunity to study the various effects of vitamin D deficiency. The morphological studies of Dodds and Cameron (1934, 1938) and the biochemical studies of Nicolaysen and Jansen (1939) are classical works on experimental rickets in the rat. However, research regarding rickets is complicated by the fact that the condition can be produced in animals by vitamin D-deficiency in combination with varying changes of the Ca: P ratio of the diet. The fact that different species respond differently to these treatments is another factor complicating studies of experimental rickets.

The mode of action of vitamin D on the calcium homeostasis is not understood. It appears, however, that there are 4 main mechanisms of action of the vitamin, i. e.

a) to stimulate the absorption of calcium and secondarily of phosphorus through the mucous membrane of the small intestine (Nicolaysen 1934, 1937, Nicolaysen and Eeg-Larsen 1953).

b) to increase the reabsorption of inorganic phosphate (Harrison and Harrison 1941) and of calcium (Gran 1960) in the kidney tubules.

c) to stimulate calcium release from mitochondria (Engstrom and DeLuca 1962, 1964 a, DeLuca et al. 1962).

d) to influence the matrix of the bone to calcify or to resorb, an effect which is, however, controversial.

As to the mode of action of vitamin D on bone there are many diverging statements in the literature and its exact mechanism of action is still unknown. Numerous experiments have provided evidence supporting the following effects of vitamin D on bone metabolism:

a) indirect on intestinal absorption of calcium and/or phosphorus (Harris and Innes 1931, Nicolaysen 1937).

b) indirect on transport of calcium through the intestinal wall to the blood serum (Harris 1932, Schachter and Rosen 1959, Dowdle et al. 1960, Wasserman 1963).

c) indirect on the parathyroid activity (Harrison et al. 1958, Rasmussen et al. 1963).

d) indirect on alkaline phosphatase activity (Zetterström 1951).

e) indirect on citrate metabolism (Schneider and Steenbock 1940, Harrison and Harrison 1952, Carlsson and Hollunger 1954, Neuman and Neuman 1958).

f) direct on bone matrix (Gyorgy 1930, Schelling 1932 b, Fischman 1937, Nicolaysen and Jansen 1939, Carlsson and co-workers 1952, 1954, 1955, Nicolaysen and Eeg-Larsen 1953 and others) an effect which, however, is still disputed.

Decalcification of the long bones by large doses of vitamin D was demonstrated histologically by Gyorgy in 1930. The action of the vitamin on calcification of bone in human rickets was first attributed to promotion of the intestinal absorption of calcium and increase of the Ca × P product in the serum, thus secondarily favoring deposition of new bone mineral. It was suggested that the defective calcification of bone in rickets depends on failure of intestinal absorption of calcium (Harris 1928, Wolbach and Bessey 1942). Nicolaysen and Jansen (1939), on the other hand, produced evidence in rats for a direct action of vitamin D on the matrix, of the skeleton, although the calcifying effect of the vitamin on rachitic bone was attributed by these authors to its effect on serum phosphate. Defective synthesis of chondroitin sulphate by the hypertrophic cartilage in rachitic bone has been described, but it was found that vitamin D has no effect on the metabolism of this substance by these cells (Hjertquist 1964)

A local calcium mobilizing action of large doses of vitamin D on bone was postulated by Schelling (1932), Barnicott (1951) and others. Carls-

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c) to stimulate calcium release from mitochondria (Engstrom and DeLuca 1962, 1964 a, DeLuca et al. 1962).

d) to influence the matrix of the bone to calcify or to resorb, an effect which is, however, controversial.

b) vitamin D promotes the calcification of the bone matrix in rickets, probably secondarily,

c) vitamin D in large doses has a calcium mobilizing effect on bone,

d) vitamin D in physiological doses promotes the calcium mobilization from the bone in a direct way, an effect which is contested and

e) the action of vitamin D on bone calcium metabolism is probably indirect.

Studies concerning the mode of action of vitamin D on bone calcium mobilization are complicated by the fact that parathyroid hormone has a known effect on calcium metabolism similar to that attributed to vitamin D.

The effect of parathyroid hormone on the mobilization of bone salt from the trabeculae of cancelous bone was demonstrated by McLean and Bloom (1941). Several other experimental studies provided further evidence for the action of the parathyroid extract on bone resorption (Barnicott 1948, Chang 1951, Grollman 1954, Greep and Kenny 1955, Gaillard 1955, 1957, Watanabee 1960, Raisz et al. 1961 and Goldhaber 1963) either indirectly through changes in the plasma level of inorganic phosphate (Albright et al 1948) or directly on the inorganic part of the bone (McLean and Urist 1955, Woods and Armstrong 1956 and Talmage and Elliot 1958) or on both the organic and inorganic part (Bronner 1960).

Work on the interaction between vitamin D and parathyroid hormone on calcium mobilization from bone goes back to the late twenties. It was observed that large doses of vitamin D given to hypocalcaemic dogs on low calcium diets, converted hypocalcemia to hypercalcemia, while corresponding doses failed to raise serum calcium levels in thyro-parathyroidectomized animals (Hess et al. 1928/29, Greenvald and Cross 1929). An opposite relation was reported several years later, i. e. lack of the calcium mobilising and hypercalcemic action of parathyroid extract in vitamin D deficient rats, unless the animals were pretreated with vitamin D (Harrison et al. 1958, Marnay and Raoul 1959, Marnay 1961) and it was, therefore, suggested that action of parathyroid hormone on mineral mobilization from bone requires the presence of vitamin D (Rasmussen et al. 1963). Other experimental studies provided, however, evidence that a definite increase in serum calcium occurs after administration of parathyroid extract to vitamin D deficient mice (Nichols et al. 1963), adult and young rats (Toverud 1964) and hens (Hertelendy and Taylor 1960).

son's work in 1952 and following years (1954, 1955) provided evidence that vitamin D in physiological doses favours the removal of lime salts from the bones. He stated that the effect of vitamin D on raising the serum calcium level and increasing growth and calcification of the skeleton were secondary to its primary effect on bone. These results were later confirmed by Nicolaysen and Eeg-Larsen (1953) and recently by Sankaran (1969). "Carlsson's effect" has, however, been contested by Migicovsky (1957). That high doses of vitamin D result in bone resorption is well documented by several experimental observations. Whether this effect of high vitamin D doses is due to a direct action on bone has been contested but seems fairly certain. However, whether physiological doses of vitamin D have this effect has been seriously contested.

During recent years the interest of several investigators has again been focused on the mode of action of vitamin D on the intestinal absorption of calcium. It is now believed that this vitamin induces the synthesis of the appropriate enzyme systems or the alteration of membrane structure necessary for calcium absorption (Norman 1966). Regarding the effect of vitamin D on bone calcification it has been stated that it seems unlikely that an additional effect of vitamin D at the calcification sites exists, but that the question remains still open (DeLuca 1967). Experimental data suggest, on the other hand, that vitamin D action on bone involves or requires a cellular component and it is not simply due to an acceleration of physicochemical exchange processes between crystal surface and extracellular fluid (Yuile et al. 1967). In studies on Ca^{45} absorption in the rachitic chick it was found that vitamin D exerts its action only after a lag time of several hours (Norman 1966). Evidence was also provided that vitamin D administration induces the formation or elaboration of a calcium binding factor by intestinal mucosa, and that this factor is a protein. The hypothesis that vitamin D acts as an initiator of enzyme synthesis in the intestinal mucosa was thus advanced (Wasserman and Taylor 1966). The work of DeLuca and co-workers (DeLuca 1969) during recent years has provided several evidence that 25-hydroxycholecalciferol is the metabolically active form of vitamin D_3 and the convertion of the latter to the former requires about 6 hours, this providing another explanation for the lag time required for the action of vitamin D.

Summarizing the evidence for an action of vitamin D on bone the following statement may be made:

a) absence of vitamin D is responsible for the defective calcification of the bone matrix in rickets,

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EFFECT OF VITAMIN D ON THYRO-PARATHYROIDECTOMIZED RATS

By

J A SEVASTIKOGLOU, M D

and

R D RAY, M D., Ph D

It seems very likely that there is an interrelationship between parathyroid hormone and vitamin D on the mobilization of bone calcium. Several theories have been advanced to explain the nature of this intererlationship. It has been stated that parathyroid hormone and crystalline vitamin D_2 act "synergistically" to enhance bone resorption (Goldhaber 1963). It has also been stated that the action of vitamin D and parathyroid hormone are "additive" in respect to their effect on calcium metabolism in bone (Nichols et al. 1963). Most accepted is, however, the concept of the "permissive" action of vitamin D, according to which the effect of vitamin D is only that of permitting the circulating parathyroid hormone to exert its characteristic effect (Rasmussen and DeLuca 1963).

The series of investigations presented herewith was initiated to determine whether vitamin D has a direct action on bone calcium metabolism. Because of the interaction between vitamin D and parathyroid hormone the first experiment was designed to investigate the effects of large and physiological doses of vitamin D on thyro-parathyroidectomized young rats. A second experiment was carried out to determine to what extent parathyroid hormone, vitamin D and calcium are essential for survival in the rat. Reports regarding the effect of parathyroid hormone on mobilization of bone calcium in vitamin D deficient animals were not in agreement and hence a third investigation was carried out. The next experiment was undertaken to examine the effect of physiological doses of vitamin D on mobilization and/or uptake of calcium by bone in well defined *in vitro* experimental system in which there was virtual absence of interaction between witamin D and other biological agents. The last study was carried out to study the effect of prolonged vitamin D deficiency on the composition of the diaphyseal cortical bone of young rats.

J. A. S.

R. D. R.

EFFECT OF VITAMIN D ON THYRO-PARATHYROIDECTOMIZED RATS[1]

By J. A. SEVASTIKOGLOU, M. D. and R. D. RAY, M. D., Ph. D.

It has been reported that large doses of vitamin D cause local mobilization of calcium from bone (Schelling 1932, Barnicott 1951). Carlsson and co-workers (1952 a, 1952 b, 1954, 1955) showed that young rats maintained on a low calcium, high phosphorus, vitamin D deficient diet, developed a low serum Ca level. When vitamin D was given to these animals in physiological doses, the serum calcium levels returned to normal. The authors concluded that "even in physiological doses, vitamin D has a marked stimulating influence on bone resorption". This effect, confirmed by Nicolaysen and Eeg-Larsen (1953) and by Sankaran (1969), has been, questioned by Migicovsky (1957).

Parathyroid hormone apparently acts in similar fashion on bone calcium mobilization (McLean and Bloom 1937, 1941, Barnicott 1948, Gaillard 1955) even in minute amounts (Gaillard 1961).

The possibility of a relationship between these two agents in their action on bone has been suspected for a long time; in fact clinical parathyroid deficiency is traditionally treated by large doses of vitamin D. Harrison et al. (1958) and later Raoul and Marnay (1960) and Rasmussen et al. (1963) provided experimental evidence that the effect of parathyroid hormone on mobilization of bone mineral requires the presence of vitamin D. This, however, has been questioned by other investigators (Hertelendy and Taylor 1960, Nichols et al. 1963, Toverud 1964).

The effect of vitamin D on bone calcium in the absence of parathyroid hormone has been investigated earlier (Hess et al. 1928/29, Greenwald and Gross 1929, Schelling 1932 a, Asher and Jones 1933) but the reported results are not conclusive.

The purpose of this investigation was to study the effect of various doses of vitamin D on skeletal retention of Ca^{45} and the serum calcium level and specific activity in thyro-parathyroidectomized rats.

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Twenty two young male Sprague-Dawley rats with a mean body weight of 75 gms were allocated in 3 groups. The rats of one group were to use as controls and those of the remaining two groups underwent thyro-parathyroidectomy 8 days before sacrifice. The rats of one of these two groups were given an excess of vitamin D. All rats were maintained on a standard laboratory ration containing 1.40 per cent calcium, 1.20 per cent phosphorus and the necessary amounts of vitamin D_3 (about 15 IU/gr diet). Food and tap water were provided *ad libitum* and the rats were housed under standard laboratory conditions.

Thyro-parathyroidectomy was performed 8 days before sacrifice under general ether anaesthesia. The thyroid together with both parathyroids were removed *in toto* at operation. The specimens were sectioned serially, stained with haematoxylin eosin and studied for histological evidence of the completeness of the operation.

Excess of vitamin D was administered by daily subcutaneous injections of 1 ml of vitamin D_2[1]) (10.000 I. U./ml) dispersion in saline for 4 consecutive days before sacrifice of the animals. The vitamin D solution was prepared daily.

Isotope studies: Six days before sacrifice all animals were injected intraperitoneally with 10 μC of Ca^{45} in 1 ml saline. After being fasted 24 hours the animals were sacrificed by bleeding from the abdominal aorta under ether anaesthesia. The blood was immediately centrifuged for 15 min. at 3.000 r. p. m. in a common laboratory centrifuge and the supernatant serum was pipetted into clean tubes and stored in the deep-freeze at —20° C until used. The hind legs of each animal were disarticulated at the knee joint and the diaphysis of both tibias of all rats were dissected free from soft tissues and periosteum. The epiphyses together with the epiphyseal cartilage plates were removed at the metaphyseal line.

The wet weights of the diaphyses were recorded. After dehydration of the bones overnight at 50° C the dry weight was determined and the bones were ashed in a muffle furnace at 700° C overnight. The ashed

[1]) Water Dispersable Vitamin D_2 (500.000 I. U per gr) General Biochem Co, Chagrin Falls, Ohio

bones were then weighed under standardized conditions, the specimens being enclosed in stoppered polyethylene vials. The water, organic and ash content of the tibiae were calculated as percentages of the wet weight. The ashed tibiae were processed to determine the specific activity by dissolving in 5 ml of a 5 per cent solution of concentrated HCl. After *the samples were completely dissolved*, the solution was diluted with distilled water to a final volume of 100 ml. A 2 ml aliquot was pipetted into a 25 ml polyethylene counting vial which was then filled with a gel scintillator. The samples were counted in a Packard Tri-carb liquid scintillation counter.

For determination of the Ca^{45} activity of the serum, 0.5 to 1.0 ml of serum was pipetted in the counting vials which were then filled with the gel scintillator and counted as above.

The total specific activity of the bones/mg ash and of the serum/ml was calculated and expressed as a percentage of the injected isotope per gram body weight.

Serum calcium determinations were performed using an Ependorf flame photometer.

RESULTS

One thyro-parathyroidectomized rat died in tetany 24 hours after the operation and was excluded from the material.

Histological examination of the tissues removed at surgery revealed that both parathyroids were totally removed in all cases.

The tibia weights were consistently lower in the thyro-parathyroidectomized rats when compared with the controls. The differences were somewhat more pronounced in thyro-parathyroidectomized rats maintained on normal doses of vitamin D than in those treated with excess vitamin D. However, the percentages of H_2O, organic material and ash showed no appreciable differences (Table I). The results of these studies were not analysed statistically.

Twenty two young male Sprague-Dawley rats with a mean body weight of 75 gms were allocated in 3 groups. The rats of one group were to use as controls and those of the remaining two groups underwent thyro-parathyroidectomy 8 days before sacrifice. The rats of one of these two groups were given an excess of vitamin D. All rats were maintained on a standard laboratory ration containing 1.40 per cent calcium, 1.20 per cent phosphorus and the necessary amounts of vitamin D_3 (about 15 IU/gr diet). Food and tap water were provided *ad libitum* and the rats were housed under standard laboratory conditions.

Thyro-parathyroidectomy was performed 8 days before sacrifice under general ether anaesthesia. The thyroid together with both parathyroids were removed *in toto* at operation. The specimens were sectioned serially, stained with haematoxylin eosin and studied for histological evidence of the completeness of the operation.

Excess of vitamin D was administered by daily subcutaneous injections of 1 ml of vitamin D_2[1]) (10.000 I. U./ml) dispersion in saline for 4 consecutive days before sacrifice of the animals. The vitamin D solution was prepared daily.

Isotope studies: Six days before sacrifice all animals were injected intraperitoneally with 10 μC of Ca^{45} in 1 ml saline. After being fasted 24 hours the animals were sacrificed by bleeding from the abdominal aorta under ether anaesthesia. The blood was immediately centrifuged for 15 min. at 3.000 r. p. m. in a common laboratory centrifuge and the supernatant serum was pipetted into clean tubes and stored in the deep-freeze at —20° C until used. The hind legs of each animal were disarticulated at the knee joint and the diaphysis of both tibias of all rats were dissected free from soft tissues and periosteum. The epiphyses together with the epiphyseal cartilage plates were removed at the metaphyseal line.

The wet weights of the diaphyses were recorded. After dehydration of the bones overnight at 50° C the dry weight was determined and the bones were ashed in a muffle furnace at 700° C overnight. The ashed

1) Water Dispersable Vitamin D_2 (500 000 I U per gr) General Biochem Co, Chagrin Falls, Ohio

The bone specific activities of the thyro-parathyroidectomized rats given vitamin D in normal or excess amounts were somewhat higher than for the normal controls. There were, however, no significant differences in bone specific activity between the groups[1]) (Table II and Fig 1).

The serum specific activities of the thyro-parathyroidectomized rats receiving vitamin D in normal amounts were much lower than for the controls. Thyro-parathyroidectomized rats on high levels of vitamin D also had lower serum activity than normal rats. In the first instance the mean values were 27 per cent and in the second 12 per cent lower than the mean values for the controls (Table II, Fig. 1). These differences were, however, not significant.

[1]) The statistical treatment of the obtained results has been based on pair comparisons using the t-test

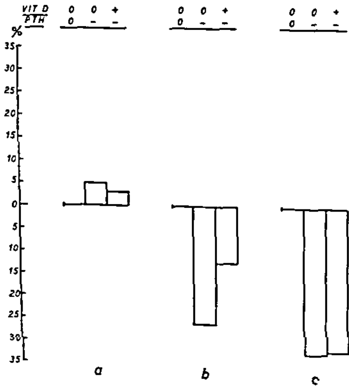


FIG 1 a) bone Ca^{45} specific activity, b) serum Ca^{45} specific activity, c) serum calcium content for the two experimental groups and the controls (left). 0 indicates a normal level, + excess, — deficiency

TABLE I. Composition of the tibia. The data represent mean values for at least 6 determinations followed by the standard deviation of the mean. 0 indicates a normal level; + excess; — deficiency.

	Vit. D. 0 PTH 0	Vit. D. 0 PTH —	Vit. D. + PTH —
Wet weight of tibia (mgs)	363.11	304.09	320.50
S. E. M.	±6.42	±4.94	±4.35
Dry weight of tibia (mgs)	232.81	199.33	206.33
S. E. M.	±3.52	±2.70	±1.99
Ash weight of tibia (mgs)	131.50	110.95	116.71
S. E. M.	±2.11	±1.87	±1.20
Percentage H_2O content of tibia	35.34	34.61	35.55
S. E. M.	±0.27	±0.38	±0.44
Percentage organic content of tibia	27.91	29.04	27.98
S. E. M.	±0.09	±0.21	±0.18
Percentage ash content of tibia	36.23	36.38	36.44
S. E. M.	±0.25	±0.25	±0.29

TABLE II. Ca^{45} specific activity of bone, serum and the serum calcium content. 0 indicates a normal level; + excess, — deficiency.

	Vit. D 0 PTH 0	Vit. D 0 PTH —	Vit. D + PTH —
Ca^{45} specific activity of tibia	2.540	2.697	2.616
S. E. M.	± 0.11	± 0.10	± 0.06
Percentage difference from the control group		+ 6.18	+ 2.99
p		> 0.05	> 0.05
Ca^{45} specific activity of the serum	0.821	0.599	0.720
S. E. M.	± 0.08	± 0.079	± 0.06
Percentage difference from the control group		—27.04	—12.30
p		> 0.05	> 0.05
Calcium content of serum (MEq per liter)	5.34	3.64	3.65
S. E. M.	± 0.071	± 0.53	± 0.34
Percentage difference from the control group		—31.83	—31.64
p		< 0.05	< 0.05

The results of the present study revealed that both normal and high levels of vitamin D administration failed to restore the serum calcium levels of thyro-parathyroidectomized rats. It must, therefore, be concluded that in the absence of the thyroid and parathyroids vitamin D did not have its characteristic hypercalcemic effect, indicating that the bone calcium mobilizing effect was not independent.

SUMMARY

Growing thyro-parathyroidectomized rats maintained on a high calcium, high phosphorus diet and normal amounts of vitamin D had no significant change in Ca^{45} retention by the skeleton. A decrease in serum specific activity was not statistically significant. There was, however, a significant decrease in the serum calcium 8 days after surgery.

Larger doses of vitamin D_2 (10 000 IU) injected subcutaneously for 4 consecutive days also failed to raise the serum calcium levels of thyro-parathyroidectomized rats.

The serum calcium content was low in the thyro-parathyroidectomized rats of both groups compared to the normal controls and these differences were significant ($p < 0.05$). There were no differences in serum calcium content between the thyro-parathyroidectomized rats of the two groups (Table II and Fig. 1).

DISCUSSION

To remove the parathyroids a total thyro-parathyroidectomy was performed because it was found in pilot experiments that was almost impossible to remove the parathyroids of these small animals without resecting large parts of the thyroid at the same time. Histological studies revealed that with parathyroidectomy alone both parathyroids were completely removed in only 25 per cent of the cases. However, in removing the thyroid a new factor was introduced, i. e. the simultaneous elimination of thyroxin and hypocalcemic effect of calcitonin. Thus the results must be considered in light of both the thyroid and parathyroid deficiency invoked to these rats.

The results of the Ca^{45} studies revealed that thyro-parathyroidectomized rats maintained on adequate amounts of vitamin D had an insignificant change in bone specific activity. The pronounced decrease of the serum specific activity was not statistically significant. In contrast to these findings, the decrease in serum calcium content 8 days after thyro-parathyroidectomy was significant. These results confirm the effects of thyro-parathyroidectomy in vitamin D fed animals reported by Rasmussen et al. in 1963.

Vitamin D in doses of 10.000 IU daily for 4 consecutive days did not cause hypercalcemia in the thyro-parathyroidectomized rat. In other words injection of large doses of vitamin D failed to restore the disturbed calcium homeostasis.

These results confirm previous observations that large doses of vitamin D failed to raise the serum calcium level in thyro-parathyroidectomized dogs (Hess et al. 1928/29, Greenwald and Gross 1929, Asher and Jones 1933). However, it has been stated that the action of vitamin D of elevating the serum calcium level is not dependent on the parathyroids (Schelling 1932, Toverud 1964).

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EFFECT OF VITAMIN D AND CALIUM ON SURVIVAL OF THE THYRO-PARATHYROIDECTOMIZED RAT

By

J A. SEVASTIKOGLOU, M. D.
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R. D. RAY, M D, Ph. D.

REFERENCES

1. Asher, D. W. and Jones, J. H.: J. Biol. Chem., *100:* 333, 1933.
2. Barnicott, N. A.: J. Anat., *82:* 233, 1948.
3. Barnicott, N. A.: J. Anat., *85:* 120, 1951.
4. Carlsson, A.: Acta Physiol. Scand., *26:* 200, 1952 a.
5. Carlsson, A.: Acta Physiol. Scand., *26:* 212, 1952 b.
6. Carlsson, A.: Acta Physiol. Scand., *31:* 308, 1954.
7. Carlsson, A. and Lindquist, B.: Acta Physiol. Scand., *35:* 53, 1955.
8. Gaillard, P. J.: Exp. Cell Res., Suppl. no. 3, 1955.
9. Gaillard, P. J.: In "The Parathyroids". Eds. Greep, R. O. and Talmage, R. V., C. C. Thomas Publ., Springfield, Ill., 1961.
10. Greenvald, I. and Gross, J.: J. Biol. Chem., *82:* 505, 1929.
11. Harrison, H. C., Harrison, H. E. and Park, E. A.: Amer. J. Physiol., *192:* 432, 1958.
12. Hertelendy, F. and Taylor, T. G.: Biochim. Biophys. Acta, *44:* 200, 1960.
13. Hess, A. F., Weinstock, M. and Rivkin, H.: Proc. Soc. Exp. Biol. (N. Y.), *26* 555, 1928/29.
14. McLean, F. C. and Bloom, W.: Science, *85:* 24, 1937.
15. McLean, F. C. and Bloom, W.: Arch. Pathol., *32:* 315, 1941.
16. Migicovsky, B. B.: Canad. J. Biochem. Physiol., *35:* 1267, 1957.
17. Nichols, G., Schartum, S. and Vaes, G. M.: Acta Physiol. Scand., *57:* 51, 1963.
18. Nicolaysen, R. and Eeg-Larsen, N.: Vitam. and Horm., *11:* 29, 1953.
19. Raoul, Y. and Marnay, C.: Acta Endocr., Suppl. no. *51*, p. 485, 1960.
20. Rasmussen, H., DeLuca, H. F., Arnaud, C., Hawker, C. and v. Stedingk, M.: J. Clin. Invest., *42:* 1940, 1963.
21. Sankaran, B.: Personal communication, 1969.
22. Schelling, D. H.: J. Biol. Chem., *96:* 215, 1932.
23. Toverud, S. U.: Acta Physiol. Scand., *62:* 391, 1964.

EFFECT OF VITAMIN D AND CALCIUM ON SURVIVAL OF THE THYRO-PARATHYROIDECTOMIZED RAT[1])

By J. A. SEVASTIKOGLOU, M. D[2]) and R. D. RAY, M. D., Ph. D.

The purpose of the following study was to determine the effect of dietary calcium on the survival of young thyro-parathyroidectomized rats, maintained on a vitamin D deficient, low phosphorus diet.

Carlsson (1952 a, 1952 b, 1954, 1955) reported that in young rats maintained on a low calcium, high phosphorus, vitamin D deficient diet with the parathyroid glands intact, vitamin D in physiological doses returned the serum calcium level to normal, presumably by mobilizing calcium from the skeleton. In an earlier study the authors found that either physiological or large doses of vitamin D failed to restore the serum calcium level to normal in young thyro-parathyroidectomized rats (Sevastikoglou and Ray 1970 a). The question thus arose as to whether young rats deprived of vitamin D, the thyroid and the parathyroids could survive when maintained on a low phosphorus and either a low or high calcium diet.

It has been reported that 7 to 11 weeks old parathyroidectomized rats can survive for 3 months when fed a high calcium, low phosphorus, vitamin D deficient diet (Asher and Jones 1933), but that fasting parathyroidectomized rats develop tetany and die within 24 hours (Jones 1938). It has also been reported that young rats on a phosphate rich, nearly calcium free ration die in less than 72 hours if both parathyroid hormone and vitamin D are lacking (Crawford et al. 1957). It has been maintained that parathyroidectomized vitamin D deficient rats can survive on a very low calcium diet, but that chicks with their parathyroids intact will die within a week when kept on a low calcium, vitamin D deficient diet (Migicovsky 1962).

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[1]) This investigation was aided by research grants from the National Institutes of Health, United States Public Health Service (grant nr 47153) and from the Swedish Medical Research Council (grant nr U-58)

[2]) Former Research Associate, Department of Orthopaedic Surgery, University of Illinois, Chicago

vitamin D deficient high calcium diet (nr. 1) and the rats in group II were maintained on a vitamin D supplemented high calcium diet (nr. 4). At the end of the 4th post operative week each group of rats was subdivided, and one subgroup was continued on the same diet and the other was placed on a low calcium diet (no. 2 and 3 respectively).

Food and distilled water were allowed *ad libitum* and the rats were kept in darkness. The body weights were recorded at intervals.

RESULTS

Histological studies showed that the thyroid and both parathyroids were completely removed in 60 cases. In four of the rats thyro-parathyroidectomy was successfully performed but because of technical problems the removal of the parathyroids could not be determined. These animals were included in the series.

The body weight changes for each experimental group are shown in Fig. 1 to 3. There were large variations during the experimental period.

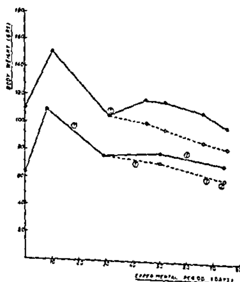


FIG 1 Body weight and mortality rate of control rats maintained on vitamin D deficient diet. Upper 6-week old rats Lower 4-week old rats. Dotted lines low calcium vitamin D deficient diet. Circles indicate the number of deaths.

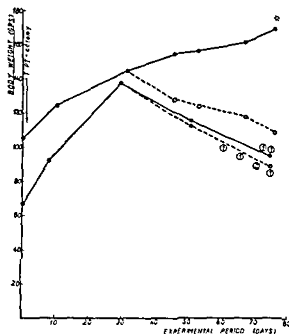


FIG. 2. Body weight and mortality of thyro-parathyroidectomized rats maintained on vitamin D supplemented diet. Upper: 6-week old rats. Lower: 4-week old rats. Dotted lines: low calcium, vitamin D supplemented diet. Circles indicate the number of deaths.

* Because of a mistake, the rats of this group received a high phosphorus diet for an unknown period of time after the 31st day.

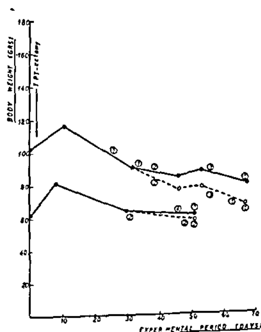


FIG 3. Body weight and mortality of thyro-parathyroidectomized rats maintained on vitamin D deficient diet. Upper 6-week old rats Lower 4-week old rats Dotted lines low calcium, vitamin D supplemented diet Circles indicate the number of deaths.

Mortality. 13 of the 64 thyro-parathyroidectomized rats died in tetany within 48 hours after the operation, 11 in the younger age group. Two more of the young rats died for reasons not connected with the surgery. Thus 49 rats remained for inclusion in the experimental final results. All of the thyro-parathyroidectomized rats on the vitamin D deficient diet, regardless of the calcium content, died within 6 to 8 weeks (Fig. 1). The younger rats died earlier than the older ones. Although some deaths occurred in the two other experimental groups, (Figs. 2 and 3) the difference between the mortality rate of the thyro-parathyroidectomized rats maintained on the vitamin D deficient diet compared with the mortality rate for the other two experimental groups was significant ($p < 0.01$)[1] (Table II).

Several of the thyro-parathyroidectomized animals developed signs of tetany soon after surgery but after the 7th postoperative day the signs of tetany disappeared. Deaths during the subsequent experimental period was preceeded by loss of body weight and development of cachaexia. Blood diarrhoea was present in several rats of the 3rd group before death.

[1]) The hypergeometric distribution was used in this case, computing the probability of a result, at least as extreme as this one, by combinatorial test

TABLE II Distribution of the material and deaths during the experimental period.

Experimental groups	Age of the rats (weeks)	No. of rats	Deaths during the experimental period
I Rats on Vit D deficient diet	6	15	1
	4	16	5
II Thyro-parathyroidectomized rats on Vit D suppl diet	6	14	0
	4	11	7
III Thyro parathyroidectomized rats on Vit D deficient diet	6	15	15
	4	11	11

DISCUSSION

The reason for removing the thyroid in order to secure complete removal of both parathyroids has been discussed earlier (Sevastikoglou and Ray 1970 a). Thus the results of this experiment must also be evaluated in light of the deficiency of both the thyroid and parathyroids.

The large variations in body weight of rats maintained on vitamin D deficient and supplemented diets and the small differences observed between thyro-parathyroidectomized and non operated animals might suggest that the vitamin rather than thyroid or parathyroid deficiency was responsible for the loss of body weight. However, reduction in the calcium content of the diet in thyro-parathyroidectomized rats also resulted in loss of body weight regardless of the amount of vitamin D in the diet. The control rats on the other hand increased in body weight when the calcium content of the vitamin D deficient diet was decreased. No explanation has been found for this observation.

As pointed out earlier it has been reported that 7 to 11 week old thyro-parathyroidectomized rats can survive for about 3 months if they are maintained on a high calcium, low phosphorus, vitamin D deficient diet (Asher and Jones 1933). The results of the present study indicated however, that 4 to 6 week old thyro-parathyroidectomized rats maintained on a low phosphorus vitamin D deficient diet did not survive more than 6 to 8 weeks regardless of the calcium content of the diet.

If the diet was supplemented with adequate amount of vitamin D the thyro-parathyroidectomized rats did survive the experimental period. This suggests that vitamin D administration in the absence of the thyroid and parathyroid glands can permit survival of rats regardless of the level of calcium in the diet. The mechanism of action of vitamin D under these circumstances is difficult to ascertain since the serum calcium levels were not determined, and the role played by the absence of the thyroid was unknown.

SUMMARY

Four and 6-week old thyro-parathyroidectomized rats did not survive when deprived vitamin D. Death occurred as a rule 6 to 8 weeks after the onset of vitamin D deficiency regardless of whether the diet contained adequate amounts of calcium or not.

Young rats with intact thyroid and parathyroid glands survived at least 8 weeks when maintained on a vitamin D deficient, low calcium diet.

Young thyro-parathyroidectomized rats maintained on a vitamin D supplemented diet with either a high or low calcium content also survived for the same experimental period.

REFERENCES

1 Asher, W D and Jones, H J · J Biol. Chem, *100* 333, 1933.
2 Carlsson, A Acta Physiol Scand., *26* 200, 1952 a.
3 Carlsson, A Acta Physiol Scand, *26* 212, 1952 b.
4 Carlsson, A Acta Physiol. Scand, *31* 308, 1954
5 Carlsson, A and Lindquist, B Acta Physiol Scand, *35* 53, 1955.
6 Crawford, J D, Gribetz, D, Diner, W C., Hurst, P. and Castleman, B · Endocrinology, *61* 59, 1957
7 Jones, H J Amer J Physiol., *122* 722, 1938
8 Migicovsky, B B In "Radioisotopes and Bone", p 161, Eds. McLean, F. C, Lacroix, P and Budy, A M, Blackwell Scient. Publ, Oxford, 1962.
9 Sevastikoglou, J A. and Ray, R D Acta Orthop. Scand, Suppl no 136, 1970 a
10 Steenbock, H and Black, A. J Biol Chem, *64* 263, 1925.

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EFFECT OF PARATHYROID HORMONE IN THE ABSENCE OF VITAMIN D

By

J. A. SEVASTIKOGLOU, M. D.

and

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EFFECT OF PARATHYROID HORMONE IN THE ABSENCE OF VITAMIN D[1])

By J. A. SEVASTIKOGLOU, M.D. and R. D. RAY, M.D., Ph.D.

Although some relationship between the action of vitamin D and parathyroid hormone on the skeleton has been suspected for many years, the exact mechanism by which they affect calcium homeostasis is not known. Furthermore there is no agreement as to whether the hypercalcemic action of parathyroid hormone is dependent on the presence of the vitamin. It has been reported that parathyroid hormone fails to raise the serum calcium level in vitamin D deficient rats (Crawford et al. 1957, Harrison et al. 1958, Marnay and Raoul 1959, Marnay 1961). Rasmussen et al. (1963) confirmed that parathyroid hormone failed to correct the hypocalcemia of vitamin D deficient rats, although when given in massive doses (2,000 I. U.) a rise in serum calcium levels did occur. The authors concluded that action of parathyroid hormone on mobilization of calcium from bone requires the presence of vitamin D. It has also been reported that a definite increase in serum calcium levels occurs following administration of parathyroid extract to vitamin D deficient hens (Hertelendy and Taylor 1960) mice (Nichols et al. 1963) adult and young rats (Toverud 1964) and dogs (Ney et al. 1965).

The purpose of the following study was to determine the effects of various dose levels of parathyroid hormone on vitamin D deficient rats.

MATERIALS AND METHODS

Twenty six young male Sprague Dawley rats with initial body weight of approximately 75 gms were divided at random into 4 experimental groups of 6 to 8 rats per group. Three groups were maintained for 27 days on a high calcium, low phosphorus, vitamin D deficient diet[2]). The

[1]) This investigation was aided by grant nr 47153 from the National Institutes of Health, U.S. Public Health Service and grants nr U-58, Y-171 and B-66-214 from the Swedish Medical Research Council

[2]) Brunius D-40 diet, composed by ground yellow corn 86 per cent; powdered egg albumin 10 per cent, iodinized NaCl 1 per cent and calcium carbonate 3 per cent.

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calcium content of the diet was 1.33 per cent and the phosphorus content 0.28 per cent. The fourth group of rats was given the same diet though supplemented with 6 IU of vitamin D_2[1]) per gr diet. Food and distilled water were given *ad libitum* and the animals were in a darkened room.

The rats of the first (control), second and third experimental groups had intact parathyroid glands. The rats in the third group were treated by excess of parathyroid extract and the rats of the fourth group were thyro-parathyroidectomized 8 days before sacrifice.

Excess parathyroid hormone was given to the animals in form of subcutaneous injections of 1 ml (100 IU) parathyroid extract[2]) daily for 4 consecutive days before sacrifice.

Thyro-parathyroidectomy was performed under ether anaesthesia. The completeness of the operation was determined as previously described (Sevastikoglou and Ray 1970 a).

Isotope studies: all rats were given 10 μC of Ca^{45} intraperitoneally 6 days before sacrifice. The specific activity of the ashed tibias was determined as described earlier (Sevastikoglou and Ray 1970 a). *The specific activity* of the bones/mg ash and of the serum/ml was calculated and expressed as a percentage of the dose of isotope per gram body weight.

The body weights were recorded at the beginning of the experiment, the day of isotope injection and the day of sacrifice.

Roentgenograms of the femurs and the paws of all the rats were taken to determine the effect of the diets on skeletal development.

Serum calcium determinations were performed using an Ependorf flame photometer.

RESULTS

One thyro-parathyroidectomized rat died in tetany within 24 hours of surgery and was excluded from the experiment. The remaining experimental and control rats survived the period of observation.

Histogical examination of the tissues removed from the rats that underwent thyro-parathyroidectomy revealed that both parathyroids were totally removed in every case.

1) Water Dispersable Vitamin D_2 (500 000 IU/gr), General Biochemicals Co, Chagrin Falls, Ohio.

2) Parathyroid extract, Eli Lilly and Co, Inc.

Roentgenologic examination of the paws and femurs of the rats on the vitamin D deficient diet revealed characteristic signs of rickets including increased width of the epiphyseal cartilage plates and irregularity of the metaphyseal areas. Control rats fed the same diet supplemented with vitamin D did not show signs of rickets but there was narrowing of the epiphyseal cartilage plates.

The changes in body weight for the rats in the four groups are summarized in Table I. All rats showed a slight increase in weight during the experimental period. There was a 35 per cent slower gain in weight for vitamin D deficient rats treated with parathyroid extract. There were no appreciable differences in body weight gains between the remaining experimental groups and the control rats maintained on the vitamin D supplemented diet

The weights and the composition of the tibias of the rats in the different groups showed no appreciable differences compared to the control animals (Table I)

TABLE I Body weight gain and composition of the tibia. The data represent mean values for at least 6 determinations followed by the standard deviations of the mean. 0 indicates a normal level, + excess, — deficiency

	Vit D 0 PTH 0	Vit D — PTH 0	Vit D — PTH +	Vit D — PTH —
Body weight gain (mgs)[1] S E M	40.16 ± 2.25	38.33 ± 2.43	25.50 ± 3.12	38.83 ± 4.03
Wet weight of tibia (mgs) S E M	223.36 ± 3.38	218.24 ± 11.05	223.86 ± 2.27	216.34 ± 3.24
Dry weight of tibia (mgs) S E M	134.03 ± 1.29	137.05 ± 2.76	129.27 ± 0.74	132.72 ± 1.87
Ash weight of tibia (mgs) S E M	62.34 ± 1.07	65.61 ± 1.95	62.37 ± 1.52	63.94 ± 1.65
Percentage H_2O content of tibia S E M	39.86 ± 0.95	37.19 ± 0.73	42.16 ± 1.31	38.59 ± 0.78
Percentage organic content of tibia S E M	32.12 ± 0.30	32.73 ± 0.41	29.91 ± 0.55	31.77 ± 0.55
Persentage ash content of tibia S E M	27.99 ± 0.78	30.00 ± 0.87	27.92 ± 0.81	29.90 ± 1.12

TABLE II. Ca^{45} specific activity of bone, serum and the serum calcium content. 0 indicates a normal level; + excess; — deficiency.

	Vit. D 0 PTH 0	Vit. D — PTH 0	Vit. D — PTH +	Vit. D — PTH —
Ca^{45} specific activity of tibia	2.197	2.176	2.153	2.164
S. E. M.	± 0.097	± 0.014	± 0.069	± 0.162
Percentage difference from the control group		— 0.96	— 2.02	— 1.50
p		> 0.05	> 0.05	> 0.05
Ca^{45} specific activity of the serum	0.716	0.822	0.864	0.565
S. E. M.	± 0.108	± 0.062	± 0.065	± 0.026
Percentage difference from the control group		+14.80	+20.67	—21.08
p		> 0.05	> 0.05	> 0.05
Serum calcium values (MEq per liter)	5.95	5.74	6.55	4.55
S. E. M.	± 0.082	± 0.142	± 0.150	± 0.255
Percentage difference from the control group		— 3.52	+10.08	—23.52
p		> 0.05	< 0.05	< 0.01

The specific activities of the tibias of all experimental groups were lower than for the control rats but the observed differences were not statistically significant[1]) (Table II and Fig. 1).

The serum specific activities showed large variations between the control and the experimental groups. Thus vitamin D deficient rats with either normal parathyroid function or excess parathyroid extract had 15 and 20 per cent higher mean values respectively as compared to the values for the control rats. The mean calcium specific activity of vitamin D deficient thyro-parathyroidectomized rats was 21 per cent lower than for the controls. The values showed, however, a large spread within each group and the differences between groups again were not significant (Table II and Fig. 1).

1) The statistical treatment of the obtained results has been based on pair comparisons using the t-test.

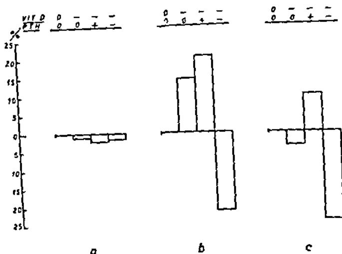


FIG. 1 a) Bone Ca^{45} specific activity, b) serum Ca^{45} specific activity, c) serum calcium content for the three experimental groups and the controls (left). 0 indicates a normal level, + excess, — deficiency.

The serum calcium content was somewhat lower in rats maintained on the vitamin D deficient diet with normal parathyroid function but the difference was not significant. Rats on the vitamin D deficient diet receiving excess parathyroid extract showed higher and thyro-parathyroidectomized vitamin D deficient rats showed lower serum calcium levels compared to the control rats (Table II and Fig. 1). The observed differences were significant ($p < 0.05$ and < 0.01 respectively).

DISCUSSION

The data on body weights and the tibia weights for the animals in the different experimental groups showed slight differences compared to the control rats and need not be discussed.

As mentioned earlier, previous reports regarding the action of parathyroid hormone on the serum calcium level of vitamin D deficient animals have been questioned. The observation that parathyroid hormone fails to raise the calcium levels in rats deprived of vitamin D (Crawford et al 1957, Harrison et al. 1958, Marnay and Raoul 1959, Marnay 1961,

Rasmusson et al. 1963) has also been challenged by the observation that administration of parathyroid extract to vitamin D deficient animals raises the serum calcium levels (Hertelendy and Taylor 1960, Nichols et al. 1963, Toverud 1964, Ney et al. 1965). The results of the present investigation support the latter observations.

As an explanation of the discrepancy between reported experimental results regarding the effect of parathyroid hormone on vitamin D deficient animals, Rasmussen et al. (1963) suggested that failure to observe dependence of parathyroid action upon vitamin D might be attributed to incomplete vitamin D deficiency. These authors were able to demonstrate that the responsiveness of bone mineral mobilization to parathyroid hormone requires only minute amounts of vitamin D (0.3 IU per rat). The vitamin D deficiency of this diet was not extreme, only sufficient to produce radiographic evidence of skeletal changes corresponding to that seen in severe deficiency. The rats used in Toverud's experiments (1964) were, however, carefully prepared to meet the requirements of extreme vitamin D deficiency of approximately the same order of magnitude as that secured by Rasmussen et al. (1963). Furthermore, the observation that vitamin D deficient rats with intact parathyroids failed to have normal serum calcium levels suggests that parathyroid hormone, at least in normal amounts, does not influence serum calcium levels in the case of incomplete vitamin D deficiency. This suggests that a hypercalcemic action of parathyroid hormone is present in vitamin D deficient rats only when given in large doses. This is, on the other hand in agreement with Rasmussen et al. observation (1963) that massive doses of parathyroid hormone, 2.000 I, U., did result in a rise of the serum calcium levels in vitamin D deficient rats. It seems, therefore, improbable that such minute difference in the degree of vitamin D deficiency, if any, could alone be responsible for the extreme variations in the results and other possible explanations for the divergence in results should be sought.

It has been reported that an increase in the Ca and P content of the diet from 0.12 to 0.24 per cent results in a significant rise in Ca and P levels of the serum of the same order of magnitude as that produced by vitamin D when added to the low mineral diet (Harrand et al. 1966). The Ca: P ratio in Toverud's stock diet was 0.52: 0.54 and in the present experiment 1.33: 0.28. The ratio in Harrison et al. experiment was 0.7: 0.56 and in Rasmussen et al. experiment 4 different diets were used with Ca: P ratios of 0.47: 0.3, 0.2· 0.3, 1 2· 0.1 and 0 02: 0 02. It is, therefore, obvious that variations in the Ca: P ratio in the diets may at least be partly responsible for the variations in reported results.

The results of the isotope studies showed that excess parathyroid extract given to vitamin D deficient rats resulted in only an insignificant decrease of isotope retention by the skeleton. This might indicate either that the calcium needed for normalization of the serum calcium values was not of such a magnitude to influence significantly the Ca^{45} retention of the bone, or that calcium was provided from extra skeletal sources as for example increased intestinal absorption or reabsorption in the kidneys. As to the serum specific activity, an increase of 20 per cent compared to the control group, occurred with excess parathyroid extract in the vitamin D deficient rats but this difference was not statistically significant. It is possible that the large spread of some of the values in this group of animals was the reason for the discrepancy.

A significant decrease of the serum calcium levels was observed in the thyro-parathyroidectomized vitamin D deficient rats. In an earlier experiment it was found that young rats treated in an identical way die within 60 days, regardless if adequate calcium was provided in the diet or not (Sevastikoglou and Ray 1970 b). No reason for the death of these rats could be advanced. The results of the present experiment suggest that prolonged severe hypocalcemia and failure of the body to regulate calcium homeostasis in the absence of both parathyroid hormone and vitamin D, might be, at least a contributory cause to the death of those animals

SUMMARY

Young rats maintained on a high calcium, low phosphorus, vitamin D deficient diet, with normal parathyroid function showed no changes in the retention of Ca^{45} by the skeleton, the serum specific activity or calcium content as compared to control rats maintained on the same diet supplemented with vitamin D

Similar rats treated with subcutaneous injections of 100 IU parathyroid extract for 4 consecutive days before sacrifice showed a significant increase in the serum calcium level The increase in serum specific activity was not statistically significant A slight but insignificant decrease of isotope retention by the skeleton was also observed.

When thyro parathyroidectomy was performed in vitamin D deficient rats there was a pronounced drop of the serum specific activity and serum calcium content but only the latter was statistically significant.

These results indicate that although normal levels of parathyroid h
mone do not affect the serum calcium content of vitamin D deficient ra
excess parathyroid extract given to such rats results in a significant
crease in the serum calcium level.

REFERENCES

1. Crawford, J. D., Gribetz, D., Diner, W. C., Hurst, P. and Castleman, B.: Endocri logy, *61: 59, 1957.*
2. Harrand, R. B., Green, R. M. and Hartles, R. L.: Br. J. Nutr., *20: 55, 1966*
3. Harrison, H. C., Harrison, H. E. and Park, E. A.: Amer. J. Physiol., *192. 432, 19*
4. Hertelendy, F. and Taylor, T. G.: Biochim. Biophys. Acta, *44: 200, 1960.*
5. Marnay, C. and Raoul, Y.: C. R. Soc. Biol. (Paris), *153· 1949, 1959.*
6. Marnay, C.: J. Physiol. (Paris), *53· 423, 1961.*
7. Ney, R. L., Au, W. Y. W., Kelly, G., Radde, I. and Bartter, F. C.: J. Clin. Inve *44: 2003, 1965.*
8. Nichols, G., Schartum, S. and Vaes, G. M.: Acta Physiol. Scand., *57. 51, 1963*
9. Rasmussen, H., DeLuca, H. F., Arnaud, C., Hawker, C. and v. Stedingk, M.: J. Cl Invest., *42· 1940, 1963.*
10. Sevastikoglou, J. A. and Ray, R. D.: Acta orthop. Scand., Suppl. no. *136, 1970 a.*
11. Sevastikoglou, J. A. and Ray, R. D.: Acta orthop. Scand., Suppl. no. *136, 1970 b.*

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EFFECT OF VITAMIN D ON BONE CALCIUM METABOLISM IN VITRO

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EFFECT OF VITAMIN D ON BONE CALCIUM METABOLISM IN VITRO[1])

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The aim of the following study was to determine whether vitamin D in moderate doses has a direct effect on uptake and/or release of calcium by bone maintained *in vitro*.

In 1932 Schelling stated that vitamin D in large doses accelerated the mobilization of calcium from bone. Barnicott (1951) implanted calvaria bone from young rats together with crystals of vitamin D into the brains of adult animals and described local bone resorption. Goldhaber (1963) maintained mice calvaria in tissue culture and found that the addition of vitamin D accelerated resorption. In all these studies very high levels of vitamin D were used.

Carlsson and co-workers (1952 a—1952 b, 1954, 1955) demonstrated that rats maintained on a low Ca, low vitamin D diet regained normal serum calcium levels when given vitamin D in physiological doses and concluded from this that vitamin D accelerated bone resorption. The observations of Carlsson were confirmed by Nicolaysen and Eeg-Larsen (1955) and most recently by Sankaran (1969). However, Sankaran also found that these animals had a significant increase in urinary calcium output as well as reduction in bone ash content. He pointed out, however, that it was impossible to conclude from *in vivo* studies whether the response was due to a direct action of vitamin D on bone. Migicovsky (1957) took exception to Carlsson's conclusions stating that "vitamin D affects the accretion rate, which in turn could bring about an increase in the resorption rate per bone" and that "it cannot be stated whether the action of the vitamin D on the bone is direct or indirect". It has been stated that the action demonstrated by Carlsson and Lindquist (1955) of physiological doses of vitamin D on the skeleton may not be direct, but could be mediated through the parathyroids with failure of calcium mobilization from the skeleton until the vitamin was administered (Harrison 1964) and that the bone mineral mobilization in response to parathyroid hormone requires minute amounts of vitamin D (Rasmussen and DeLuca 1963).

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MATERIAL AND METHODS

Two experiments were conducted: the first on *release* of Ca^{45} from bone to the medium and the second on *uptake* of Ca^{45} by bone from the medium. For each experiment six-week old, Long Evans rats were allocated to two groups. The first group was fed a high calcium, low phosphorus, vitamin D deficient diet (Steenbock and Black 1925) for 18 days. The second group was fed the standard laboratory ration. Chemical determinations of the Ca and P content of the diets showed that the vitamin D deficient diet contained 2.33 per cent Ca and 0.28 per cent P. The respective figures for the standard diet were 2.32 per cent and 1.48 per cent.

Incubation medium: Two types of media were used (NCTC-109 Evans 1956 a and 1956 b)[1]: Vitamin D was omitted from one. The other contained 1 mg of vitamin D_2 per liter[2], dissolved in 4 ml of 95 per cent ethanol.

In the studies on *release* of calcium from bone each animal was injected intraperitoneally with 10 μC Ca^{45} three days prior to sacrifice. No radioactive isotopes or streptomycin were added to the medium.

In studies on *uptake* of calcium by bone 0.033 μc Ca^{45} per ml, and 0.05 mg streptomycin per ml were added to the medium.

Preparation of the samples for incubation: After sacrifice by ether, the rats were depilated and bathed for a short while in an antiseptic solution. The hind legs were then disarticulated at the hip joint. Under sterile conditions the diaphysis of each tibia was dissected free from soft tissues and periosteum, and the epiphyses together with the epiphyseal cartilage plates were removed at the metaphyseal line. Each bone was split longitudinally, the marrow was carefully removed and the bone fragments washed in warm nutrient medium to remove adherent soft tissues and blood. The size of the fragments varied but their thickness as a rule did not surpass 0.5 mm. The fragments from the one tibia were transferred to a 30 ml plastic test tube, and 5 ml of the first type of medium were pipetted into the tube. The fragments from the controlateral tibia of the same animal[3]) were placed in another test tube and

[1]) The media were prepared and delivered in 100 ml sterile vials by Grand Island Biological Company, Grand Island, N Y

[2]) General Biochemicals Co., Chagrin Falls, Ohio

[3]) The wet-, dry-, and ash weights as well as the Ca^{45} specific activity of the tibias of the same animals were studied in pilot experiments Minor differences observed between the values of the two tibias were not statistically sifnificant

the same amount of the second medium was added. The tubes were sealed with rubber stoppers and placed in a roller tube apparatus, in an incubator at 37° C for 72 hours.

In the *uptake* experiment, in addition to living bone, killed bone fragments were also maintained in the culture medium in a parallel series of experiments. The fragments were boiled for 15 minutes in saline and then incubated. The killed samples served as controls for the viability of the living specimens.

Preparation of the samples for counting: At the end of 72 hours the bone fragments were removed from the incubation tubes, weighed and placed in a muffle furnace at 700° C overnight for ashing and the ash weight determined. The ashed bone fragments were processed for specific activity determinations as described earlier (Sevastikoglou and Ray 1970 a).

Determination of the specific activity of the medium was performed at the end of incubation and after removal of the bone fragments from the tubes. Three ml of the solution were pipetted into plastic counting vials which were filled with gel scintillator and counted in a liquid scintillation counter. The specific activities of the samples were calculated as follows: a) for the *release* experiment as counts per minute per 5 ml medium expressed as a percentage of the total (bone and medium) activity and b) and for the *uptake* experiment as counts per minute per mg ash weight of the incubated bone.

Studies of bone viability Determinations of the pH of the medium before and at the end of incubation (initial and final pH) as well as of blank samples incubated for 72 hours in the absence of bone, were performed Furthermore, the pH of the medium in which fragments of killed bone were incubated for 72 hours was also determined.

Sections of living and killed bone, before and after 72 hours incubation, were examined histologically after haematoxylin eosin staining.

Analysis of variance was used for statistical evaluation of the results.

RESULTS

Bacterial contamination of the cultures was rare. When this occurred, the affected cultures were excluded from the study.

The initial and final pH of the culture media are given in Table I.

TABLE I. pH variations of the medium. The values represent the means for at least 3 pH determinations followed by the standard deviation of the mean.

	Release experiment		Uptake experiment		
	Living bone samples	Blanks	Living bone samples	Dead bone samples	Blanks
Initial pH	7.37 ± 0.03	7.37 ± 0.03	7.82 ± 0.07	7.82 ± 0.07	7.82 ± 0.07
Final pH	7.39 ± 0.02	8.47 ± 0.12	7.68 ± 0.01	8.14 ± 0.04	8.42 ± 0.07

Histological studies: Sections of boiled bone showed a very intense eosiniphilic staining throughout. Few empty lacunae were present. At high magnification shrinkage of the osteocyte nuclei was apparent. Sectioned specimens both before and after incubation had exactly the same appearance and no microscopic changes in the structure of the bone occurred during incubation. The living bone specimens showed normal staining characteristics. Sections of fresh non-incubated bone had a normal histological appearance. However, incubated specimens showed scattered empty lacunae as well as areas with cell occupied lacunae. The nuclei of the bone cells were round and had a healthy appearance. The living bone areas were by far more abundant and larger than the devitalized bone areas.

The specific activity of the medium in the *release* experiment (Table II) was found to be higher with bone from the vitamin D deficient, than from the normal rats, the difference being highly significant. The minor differences between the specific activities of the medium containing vitamin D and deprived of vitamin D were not significant.

TABLE II *Release* experiment. The medium Ca^{45} specific activity after 72 hours of incubation. The values represent the means of 7 determinations followed by the standard deviation of the mean.

		Vitamin D deficient medium	Vitamin D containing medium	P
Ca^{45} specific activity per 5 ml medium as percentage of the total (bone + medium) activity	Vitamin D deficient rats	3.584 ± 0.331	3.610 ± 0.295	>0.05
	Normal rats	1.180 ± 0.050	1.109 ± 0.067	>0.05
	P	<0.001	<0.001	

TABLE III. *Uptake* experiment. The bone Ca^{45} specific activity after 72 hours of incubation. The values represent means of 7 determinations followed by the standard deviation of the mean.

		Vitamin D deficient medium	Vitamin D containing medium	p
Bone Ca^{45} specific activity (counts per min per mg ash)	Vitamin D deficient rats	146.02 ± 4.85	142.44 ± 5.42	> 0.05
	Normal rats	96.10 ± 2.36	90.90 ± 3.31	> 0.05
	p	< 0.001	< 0.001	

Bone derived from vitamin D deficient animals showed a significantly higher *uptake* of Ca^{45} *in vitro* than bone from normal rats (Table III). Again there was no variance in specific activity between samples incubated in a vitamin D free and vitamin D containing medium.

DISCUSSION

The question of whether the "living" bone fragments were really viable is of paramount importance in interpretating the results. It has been reported that the *in vitro* uptake of Sr^{90} by *devitalized bone is equal to* that of living bone. Mobilization of Sr^{90} is, on the other hand much higher from living than from devitalized bone (Ray et al. 1955).

Several reports indicate that embryonic bone cultivated in protein free synthetic media survives with morphological and metabolic evidence of activity (Wolff et al. 1953, Kieny 1955, Biggers et al. 1957, 1961, Lengenmann 1962, Gorham and Waymouth 1965). The medium used in these earlier experiments was similar to the medium used in the present study.

The final pH of the medium used to maintain the "living" bone showed a slight shift from the initial pH and was obviously lower than the final pH of the blanks. The final pH of the samples in which killed bone was incubated was considerably higher than the initial pH, almost as high as the final pH of the blanks. This might be explained by the assumption that *some metabolic activity of "living" bone* preserved the final pH of the buffered medium at the initial level. When no cellular activity was involved the final pH shifted to an alkaline level, as observed in the blanks and the case of incubated samples of killed bone. In metabolic studies of "living" bone fragments *in vitro* using no buffered (Basett and Nordin 1959) *or buffered media* (Shartum and Nichols 1961) only minor changes in the pH were recorded after 48 *or 16 hours* respectively. The

solubility of bone mineral was found to be independent within the observed pH range (Shartum and Nichols 1961).

Histological study of the boiled bone showed that the fragments were devitalized before incubation and that no morphological changes occurred during incubation. Contrary "living" bone fragments revealed a healthy appearance after incubation throughout the section. Minor populations of dead cells merging into areas of bone of normal appearance were also present. Death of certain portions of the incubated bone fragments was expected as a result of uneven thickness of the fragments and hence uneven conditions of nutrition.

The pH and the morphological studies suggest that the bone fragments remained viable during incubation.

In vitro investigations concerning the effect of vitamin D on bone have been carried out earlier by several authors. Shipley et al. (1925) and Howland (1925) reported that epiphyseal cartilage from rachitic rats placed in the serum of rachitic rats did not calcify, but did calcify when placed in serum from non-rachitic rats. Fischmann (1937) observed that osteogenic tissue cultivated in blood serum derived from normal roosters developed and calcified well, but if serum from vitamin D deficient animals was used osteoid tissue and abnormal non-calcified cartilage formed. Rat calvaria maintained in a medium composed of chicken plasma and embryo extract as well as horse serum showed marked bone resorption when large doses of dihydrotachysterol and crystalline vitamin D_2 or D_3 were added. The simultaneous addition of parathyroid extract (0.1 U per ml) and crystalline vitamin D_2 (0.01 mg per ml) resulted in "synergistic enhancement of bone resorption" (Goldhaber 1963). Mice calvaria from vitamin D deficient animals pretreated with vitamin D or parathyroid extract were maintained in buffered Krebs-Ringer solution for 16 hours. Studies of the mobilization of calcium, phosphorus and citrate by bone led to the conclusion that vitamin D appears to modify the metabolism of bone fragments *in vitro* in a fashion similar to that following treatment with parathyroid hormone. It was, therefore, stated that is likely that vitamin D and parathyroid hormone are "additive in respect to their actions on calcium metabolism of bone" (Nichols et al. 1963). A similar effect of vitamin D on rat calvaria maintained *in vitro* and pretreated with vitamin D was reported later by Au and Bartter (1966). It has been reported, on the other hand, that vitamin D has no effect on calcification of hypertrophic cartilage maintained *in vitro* (Robison 1934) and that the addition of vitamin D in alcoholic or aqueous solution or sera from animals treated with large doses of vitamin D in

embryonic rat bone cultures maintained on a mixture of equal parts of serum and modified Eagle's medium did not stimulate bone resorption directly (Raisz 1965). The present results are thus in agreement with those of Robison and Raisz but disagree with the results of the other authors referred on above.

An explanation for the divergence in the reported effect of vitamin D on the *resorption of bone in vitro* may be the existence or not of parathyroid hormone on the used systems. As mentioned elsewhere there are several studies suggesting an interrelationship between vitamin D and parathyroid hormone in their action on bone (*Harrison et al.* 1958, Marnay and Raoul 1959, Marnay 1961, Newman and Dowse 1961, Rasmussen et al. 1963). There are also reports that such an interaction does not really exist (Hertelendy and Taylor 1960, Nichols et al. 1963, Toverud 1964) and it has been stated that the fact that the controversy exists requires that the question remains open (Munson et al. 1963). If such an interrelationship exists the experimental systems used by Goldhaber, Nichols et al and Au and Bartter do not eliminate the possible intervention of parathyroid hormone. In his tissue culture media Goldhaber used biological substances such as plasma, embryo extract and serum, which *probably contain some parathyroid hormone Furthermore the vitamin D* doses used by Goldhaber were by far larger, approximately 100 times, than those used in the present study Nichols et al. and Au and Bartter *in their experiment pretreated the vitamin D deficient animals with vitamin* D before the bones were removed and maintained in the *in vitro* system. A prior interaction between vitamin D and parathyroid hormone, therefore, can not be excluded. The failure of vitamin D to mobilize calcium despite the presence of serum and hence parathyroid hormone in the used culture medium in Raisz's experiment makes however, this possibility questionable

The question arises as to whether vitamin D was *really active in the* vitamin D supplemented medium, since it has been demonstrated that the activity of the vitamin may vary considerably under different experimental conditions such as temperature or oxygen *or the presence or absence of* lipids and or proteins in the solution (Evans 1964, Chen and Lane 1965). There is no way to give a direct answer to this question with the available data, but the method of *preparation of the vitamin D is considered to be* compatible with tissue culture work Evans and co-workers (1964) reported that bone cells derived from human femur could be kept alive in NCTC 109 culture medium containing 0.25 *mg/liter* vitamin D_2 for 761 days

It seems more appropriate to correlate the divergence in the reported results to the possibility of vitamin D to be converted to its metabolite, described by Lund and DeLuca (1966), now known as 25-hydroxycholecalciferol. It has been shown most recently that addition of this metabolite stimulates definetely the resorption of fetal rat bone cultured in a chemically defined medium (Trummel et al. 1969). According to DeLuca (1969) "it appears almost certain" that 25-hydroxycholecalciferol is the metabolically active form of vitamin D and that the liver is necessary to activate vitamin D by converting it to its 25-hydroxy-derivative. However, this hypothesis too can not explain the results reported by Goldhaber. It is, therefore, obvious that there is no way to give a satisfactory explanation for the divergence in the reported results regarding the action of vitamin D on bone resorption *in vitro*.

Another observation made in this study was that the *in vitro* metabolic rate of Ca^{45}, both mobilization and uptake, was significantly higher in bone derived from vitamin D deficient rats than from normal animals, regardless of whether vitamin D was added to the medium or not. It has been reported that the uptake of calcium tracers by bone derived from rachitic animals *in vivo*, compared with that from animals treated with vitamin D, is the same (Harrison and Harrison 1950) or decreased (Greenberg 1945, Carlsson 1951, Hurni et al. 1957) and compared to normal animals is either equal (Harrison and Harrison 1950) or decreased (Jones and Copp 1951, Hurni et al. 1957, Bohr 1961). Furthermore, it has been found that during the first hours after intravenous administration of radiocalcium or strontium, both normal and rachitic bones take up almost equal amounts of isotope. After twenty-four hours the retention by rachitic bones was half that of normal bone (Bohr 1964). This difference in isotope retention by bone in normal and vitamin D deficient rats has been attributed to an increased excretion in the urine of the rachitic animals, mainly because of the higher specific activity of radiocalcium in the blood (Bohr 1964).

In the present study however, bone from rats maintained on the vitamin D deficient diet showed a significantly higher mobilization of isotope than normal bone and furthermore, bone from vitamin D deficient rats maintained in a Ca^{45} containing medium showed also a significantly higher isotope uptake than normal bone. These observations indicate that the metabolic activity of bone derived from vitamin D deficient rats has a significantly higher calcium turnover rate than bone derived from normal animals and as expressed in this experiment, increased mobilization as well as uptake of Ca^{45}. The latter fact is in agreement with reports

that bone from rachitic rats takes up more vitamin D than from normal stock rats (Kodiçek and Thompson 1965, Neville and DeLuca 1966) but disagrees with the statement that "rachitic bone takes up as much minerals as the normal bone when identical amounts of Ca and P are supplied to it" (Nicolaysen and Eeg-Larsen 1953). It must be pointed out in this context that the composition of the diet given to the rats of the two groups was different with regard to the Ca and P content, which might be the reason of the different metabolic activity of the bones.

SUMMARY

Bone fragments from vitamin D deficient and normal young rats were *incubated for 72 hours in a NCTC-109 synthetic culture medium*, with or without supplemental vitamin D_2 (0.1 mg %).

Maintainance of physiologic pH by "living" bone fragments confirmed histologic evidence of viability of the explants after the 72 hour experimental period.

Studies of the calcium metabolism by means of Ca^{45} either injected to the rats prior to sacrifice or alternatively added to the medium indicated that:

a) Ca^{45} *uptake* by and *release* from bone obtained from vitamin D deficient and normal rats was not affected by the addition or not of vitamin D in the *in vitro* system used in this experiment.

b) *the release* and *uptake* of Ca^{45}, *in vitro* was significantly higher for bone from vitamin D deficient than from normal rats.

REFERENCES

1 Au, W Y W and Bartter, F C. Endocrinology, *78* 1100, 1966
2 Basett, C A and Nordin, B F C Acta Orthop Scand, *28* 241, 1959
3 Barnicott, N A J Anat, *85* 120, 1951
4 Biggers, J D, Webb, M, Parker, R C and Healy, G M. Nature, *180* 825, 1957.
5 Biggers, J D, Gwatkin, R B L *and Heyner, S Exp. Cell Res*, *25* 42, 1961.
6 Bohr, H H Acta Orthop Scand, *30* 231, 1961
7 Bohr, H H Acta Physiol Scand., *60* 94, 1964
8 Carlsson, A Acta Pharmacol (Kpn), *7* Suppl no 1, 1951.
9 Carlsson, A Acta Physiol Scand, *26* 200, 1952 a
10 Carlsson, A Acta Physiol Scand, *26* 212, 1952 b.
11 Carlsson, A Acta Physiol Scand., *31* 308, 1954
12 Carlsson, A and Lindquist, B Acta Physiol Scand, *35* 53, 1955
13 Chen, P S, Terepka, R A, Lane, K and Marsh, A Analyt Bioch., *10* 421, 1965.
14 DeLuca, H F New England Med J, *181* 1103, 1969

It seems more appropriate to correlate the divergence in the reported results to the possibility of vitamin D to be converted to its metabolite, described by Lund and DeLuca (1966), now known as 25-hydroxycholecalciferol. It has been shown most recently that addition of this metabolite stimulates definetely the resorption of fetal rat bone cultured in a chemically defined medium (Trummel et al. 1969). According to DeLuca (1969) "it appears almost certain" that 25-hydroxycholecalciferol is the metabolically active form of vitamin D and that the liver is necessary to activate vitamin D by converting it to its 25-hydroxy-derivative. However, this hypothesis too can not explain the results reported by Goldhaber. It is, therefore, obvious that there is no way to give a satisfactory explanation for the divergence in the reported results regarding the action of vitamin D on bone resorption *in vitro*.

Another observation made in this study was that the *in vitro* metabolic rate of Ca^{45}, both mobilization and uptake, was significantly higher in bone derived from vitamin D deficient rats than from normal animals, regardless of whether vitamin D was added to the medium or not. It has been reported that the uptake of calcium tracers by bone derived from rachitic animals *in vivo*, compared with that from animals treated with vitamin D, is the same (Harrison and Harrison 1950) or decreased (Greenberg 1945, Carlsson 1951, Hurni et al. 1957) and compared to normal animals is either equal (Harrison and Harrison 1950) or decreased (Jones and Copp 1951, Hurni et al. 1957, Bohr 1961). Furthermore, it has been found that during the first hours after intravenous administration of radiocalcium or strontium, both normal and rachitic bones take up almost equal amounts of isotope. After twenty-four hours the retention by rachitic bones was half that of normal bone (Bohr 1964). This difference in isotope retention by bone in normal and vitamin D deficient rats has been attributed to an increased excretion in the urine of the rachitic animals, mainly because of the higher specific activity of radiocalcium in the blood (Bohr 1964).

In the present study however, bone from rats maintained on the vitamin D deficient diet showed a significantly higher mobilization of isotope than normal bone and furthermore, bone from vitamin D deficient rats maintained in a Ca^{45} containing medium showed also a significantly higher isotope uptake than normal bone. These observations indicate that the metabolic activity of bone derived from vitamin D deficient rats has a significantly higher calcium turnover rate than bone derived from normal animals and as expressed in this experiment, increased mobilization as well as uptake of Ca^{45}. The latter fact is in agreement with reports

that bone from rachitic rats takes up more vitamin D than from normal stock rats (*Kodiçek and Thompson 1965, Neville and* DeLuca 1966) but disagrees with the statement that "rachitic bone takes up as much minerals as the normal bone when identical amounts of Ca and P are supplied to it" (Nicolaysen and Eeg-Larsen 1953). It must be pointed out in this context that the composition of the diet given to the rats of the two groups was different with regard to the Ca and P content, which might be the reason of the different metabolic activity of the bones.

SUMMARY

Bone fragments from vitamin D deficient and normal young rats were incubated for 72 hours in a NCTC-109 synthetic culture medium, with or without supplemental vitamin D_2 (0.1 mg %).

Maintainance of physiologic pH by "living" bone fragments confirmed histologic evidence of viability of the explants after the 72 hour experimental period.

Studies of the calcium metabolism by means of Ca^{45} either injected to the rats prior to sacrifice or alternatively added to the medium indicated that:

a) Ca^{45} *uptake* by and *release* from bone obtained from vitamin D deficient and normal rats was not affected by the addition or not of vitamin D in the *in vitro* system used in this experiment.

b) *the release* and *uptake* of Ca^{45}, *in vitro* was significantly higher for bone from vitamin D deficient than from normal rats.

REFERENCES

1 Au, W Y W and Bartter, F C. Endocrinology, 78 1100, 1966
2 Basett, C A and Nordin, B E C Acta Orthop Scand, 28 241, 1959.
3 Barnicott, N A J Anat, 85 120, 1951
4 Biggers, J D, Webb, M, Parker, R C and Healy, G. M Nature, 180 825, 1957.
5 Biggers, J D, Gwatkin, R B L. and Heyner, S Exp Cell Res, 25 42, 1961.
6 Bohr, H H Acta Orthop Scand, 30 231, 1961
7 Bohr, H H Acta Physiol Scand, 60 94, 1964
8 Carlsson, A Acta Pharmacol (Kpn), 7 Suppl no 1, 1951
9 Carlsson, A Acta Physiol Scand., 26 200, 1952 a
10 Carlsson, A Acta Physiol Scand., 26 212, 1952 b
11 Carlsson, A Acta Physiol Scand., 31 308, 1954
12 Carlsson, A and Lindquist, B Acta Physiol Scand., 35 53, 1955
13 Chen, P S, Terepka, R A, Lane, K and Marsh, A. Analyt. Bioch, 10 421, 1965.
14 *DeLuca, H F* New England Med *J*, *181* 1103, 1969

15. Evans, V. J., Fioramonti, M. C., McQuilkin, W. T., Sandford, K. K. and Earle, W. R.: Cancer Res., *16*: 77, 1956 a.
16. Evans, V. J., Bryant, J. C., McQuilkin, W. T., Fioramonti, M. C., Sanford, K. K., Westfall, B. and Earle, W. R.: Cancer Res., *16*: 87, *1956* b.
17. Evans, V. J., Bryant, J. C., Kerr, H. A. and Schilling, E. L.: Exp. Cell. Res, *36* 439, 1964.
18. Fischmann, J.: Arch. f. exp. Zellforsch., *19*: *211*, 1937.
19. Goldhaber, P.: In "Mechanism of Hard Tissue Destruction". Ed. Sognnaes R. F, Am. Ass. Adv. Sc., Washington, D. C., *1963*.
20. Gorham, L. M. and Waymouth, C.: Proc. Soc. Exp. Biol. Med., *119*: 287, 1965.
21. Greenberg, D. M.: J. Biol. Chem., *157*: *99*, *1945*.
22. Harrison, H. E. and Harrison, H. C.: J. Biol. Chem., *185*: *857*, *1950*.
23. Harrison, H. E., Harrison, H. C. and Park, E. A.: Amer. J. Physiol, *192*: 432, 1958
24. Harrison, M. T.: Postgrad. Med. J., *40*: 497, 1964.
25. Hertelendy, F. and Taylor, T. G.: Biochim. Biophys. Acta, *44*: 200, *1960*
26. Howland, J.: Medicine (Baltimore) *2*: 349, *1923*.
27. Hurni, H, Minder, W. and Gordonoff, T.: Int. Z. Vitamin-forsch, 28: 68, 1957
28. Jones, D. C. and Copp, D. H.: J. Biol. Chem., *189*: *509*, *1951*.
29. Kieny, M.: C. R. Soc. Biol. (Paris), *149*: *418*, *1955*.
30. Kodiçek, E. and Thompson, G. A.: In "Structure and Function of Connective and Skeletal Tissue". Eds. Fitton Jackson, S., Harkness, R. D., Partridge, S M and Tristram, G. R. Butterworth London and Washington, *1965*.
31. Lengemann, F. W.: Endocrinology, *70* 774, *1962*.
32. Lund, J. and DeLuca, H. F.: J. Lipid Res., *7*: 739, *1966*.
33. Marnay, C.: J. Physiol., *53*: 423, *1961*.
34. Marnay, C. and Raoul, Y.: C. R. Soc. Biol (Paris), *153* 1949, *1959*.
35. Munson, L. P., Hirsch, F R. and Tashjian, H. A.. Ann Rev. Physiol., *25* 325, 1963.
36. Migicovsky, B. B. Canad J. Bioch Physiol., 35 1267, 1957.
37. Neville, P. F. and DeLuca, H. F.. Biochemistry, *5* 2201, *1966*
38. Neuman, W F. and Dowse, C. M In "The Parathyroids" Eds Greep, R O. and Talmage, R V, C C Thomas Publ., Springfield, Ill., 1961
39. Nichols, G, Schartum, S and Vaes, G. M. Acta Physiol Scand, *57* 51, *1963*.
40. Nicolaysen, R and Eeg-Larsen, N. Vitam and Horm, *11* 29, *1953*
41 Rasmussen, H. and DeLuca, F. F.: Ergebn Physiol, *53* 108, 1963
42. Rasmussen, H, DeLuca, H. F, Arnaud, C., Hawker, C. and v. Stedingk, M. J Clin Invest., *42* 1940, *1963*.
43 Raisz, L. G J Clin. Invest, *44* 103, *1965*.
44. Ray, R. D., La Violette, D., Buckley, H D. and Mosiman, R S. J Bone Jt. Surg, *37-A*. 143, 1955.
45. Robison, R.: Biochem. J., *28* 684, 1934
46 Sankaran, B. Personal communication, 1969.
47. Schartum, S. and Nichols, G: J Clin. Invest, *40* 2083, *1961*.
48. Schelling, D. H: J. Biol Chem, *96* 215, 1932
49. Sevastikoglou, J. A and Ray, R. D.: Acta Orthop Scand, Suppl no 136, 1970 a
50. Shipley, P. G, Kramer, B and Howland, J Amer J Dis Child, *30* 37, 1925
51. Steenbock, H. and Black, A J Biol. Chem., *64* 263, *1925*
52 Toverud, S U.: Acta Physiol Scand, 62 391, 1964.
53. Trummel, C. L, Raisz, L. G., Blunt, J W and DeLuca, H F Science, *163* 1450, 1969
54. Wolff, E., Haffen, K., Kieny, M and Wolff, E. J Embryol. Exp Morph *1* 55, 1953.

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CHEMICAL STUDIES OF CORTICAL DIAPHYSEAL BONE DURING VITAMIN D DEFICIENCY IN THE RAT

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15. Evans, V. J., Fioramonti, M. C., McQuilkin, W. T., Sandford, K. K. and Earle, W. R.: Cancer Res., *16*: 77, 1956 a.
16. Evans, V. J., Bryant, J. C., McQuilkin, W. T., Fioramonti, M. C., Sanford, K. K., Westfall, B. and Earle, W. R.: Cancer Res., *16*: 87, 1956 b.
17. Evans, V. J., Bryant, J. C., Kerr, H. A. and Schilling, E. L.: Exp Cell. Res., *36* 439, 1964.
18. Fischmann, J.: Arch. f. exp. Zellforsch., *19*: 211, 1937.
19. Goldhaber, P.: In "Mechanism of Hard Tissue Destruction". Ed. Sognnaes R. F., Am. Ass. Adv. Sc., Washington, D. C., 1963.
20. Gorham, L. M. and Waymouth, C.: Proc. Soc. Exp. Biol. Med., *119*. 287, 1965.
21. Greenberg, D. M.: J. Biol. Chem., *157*. 99, 1945.
22. Harrison, H. E. and Harrison, H. C.: J. Biol. Chem., *185*: 857, 1950.
23. Harrison, H. E., Harrison, H. C. and Park, E. A.: Amer. J. Physiol., *192*: 432, 1958.
24. Harrison, M. T.: Postgrad. Med. J., *40*: 497, 1964.
25. Hertelendy, F. and Taylor, T. G.: Biochim. Biophys. Acta, *44*. 200, 1960.
26. Howland, J.: Medicine (Baltimore) *2*: 349, 1923.
27. Hurni, H., Minder, W. and Gordonoff, T.: Int Z. Vitamin-forsch., *28*: 68, 1957.
28. Jones, D. C. and Copp, D. H.: J. Biol. Chem., 189: 509, 1951.
29. Kieny, M.: C. R. Soc. Biol. (Paris), *149*: 418, 1955.
30. Kodiçek, E. and Thompson, G. A.: In "Structure and Function of Connective and Skeletal Tissue". Eds. Fitton Jackson, S., Harkness, R. D., Partridge, S. M. and Tristram, G. R. Butterworth London and Washington, 1965.
31. Lengemann, F. W.: Endocrinology, *70*: 774, 1962.
32. Lund, J. and DeLuca, H. F.: J. Lipid Res., *7*: 739, 1966.
33. Marnay, C.: J. Physiol., *53*. 423, 1961.
34. Marnay, C. and Raoul, Y.: C. R. Soc. Biol. (Paris), *153* 1949, 1959.
35. Munson, L. P., Hirsch, F. R. and Tashjian, H. A. Ann Rev. Physiol., *25*. 325, 1963
36. Migicovsky, B. B.: Canad. J. Bioch. Physiol., *35*: 1267, 1957.
37. Neville, P. F. and DeLuca, H. F.: Biochemistry, *5* 2201, 1966.
38 Neuman, W. F. and Dowse, C M: In "The Parathyroids". Eds. Greep, R. O. and Talmage, R. V., C. C. Thomas Publ., Springfield, Ill., 1961.
39. Nichols, G., Schartum, S. and Vaes, G M. Acta Physiol. Scand., *57* 51, 1963.
40. Nicolaysen, R and Eeg-Larsen, N.: Vitam. and Horm., *11*. 29, 1953.
41. Rasmussen, H. and DeLuca, F. F Ergebn. Physiol., *53* 108, 1963.
42. Rasmussen, H., DeLuca, H F, Arnaud, C., Hawker, C. and v. Stedingk, M: J. Clin Invest., *42*: 1940, 1963
43. Raisz, L. G. J. Clin Invest., *44* 103, 1965.
44. Ray, R D, La Violette, D, Buckley, H. D. and Mosiman, R. S. J Bone Jt. Surg., *37-A* 143, 1955.
45. Robison, R Biochem J, *28* 684, 1934.
46. Sankaran, B Personal communication, 1969
47 Schartum, S and Nichols, G J Clin Invest, *40* 2083, 1961
48. Schelling, D H J Biol Chem, *96* 215, 1932.
49 Sevastikoglou, J A and Ray, R D.. Acta Orthop Scand, Suppl no 136, 1970 a
50. Shipley, P G, Kramer, B and Howland, J Amer J Dis Child, *30* 37, 1925
51 Steenbock, H and Black, A J Biol. Chem., *64* 263, 1925
52 Toverud, S U Acta Physiol Scand, *62* 391, 1964.
53 Trummel, C L., Raisz, L G, Blunt, J. W and DeLuca, H F. Science, *163* 1450, 1969.
54 Wolff, E., Haffen, K., Kieny, M and Wolff, E.: J Embryol Exp Morph *1* 55, 1953.

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CHEMICAL STUDIES OF CORTICAL DIAPHYSEAL BONE DURING VITAMIN D DEFICIENCY IN THE RAT

By

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CHEMICAL STUDIES OF CORTICAL DIAPHYSEAL BONE DURING VITAMIN D DEFICIENCY IN THE RAT[1])

By S.-O. HJERTQUIST, M. D., E. BERGQUIST, M. D.
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The effect of vitamin D on bone metabolism in general and on the defective calcification of newly formed rachitic bone matrix in particular, is not fully understood. The results of earlier experimental studies of vitamin D deficiency and bone metabolism have not been consistent and indeed have often been contradictory. It is known that young animals maintained on a vitamin D deficient, low phosphorus diet develope pronounced morphological changes comparable to those observed in human rickets, with accompanying disturbances in the inorganic composition of the skeleton. However, studies of the chemical composition of the organic component of rachitic bone are few and almost exclusively confined to the epiphyseal cartilage and metaphyseal bone. (Harris 1956, Irving 1957, Follis 1958, 1960, Engfeldt and Hjertquist 1960, Fourman et al. 1968).

It has been reported that the hexosamine content of epiphyseal cartilage of rats with healing rickets is decreased compared with rachitic cartilage (Dikshit 1959). A slight increase in hexosamine content of rachitic chicken cartilage 48 hours after administration of vitamin D has also been reported (Cipera et al. 1960). In the latter case no changes in the ash content was found. Studies of acetone dried epiphyseal cartilage powder from normal and rachitic puppies as well as from puppies with healing rickets revealed that rachitic cartilage had a higher content of glycosaminoglycans than normal calculated per organic dry weight. Healing rachitic and rachitic cartilage did not show any significant differences (Hjertquist 1964 a). On the other hand no conclusive differences were found in total hexosamine concentration on the basis of organic dry weight or the concentration of various glycosaminoglycans comparing mineralised and non mineralised epiphyseal cartilage zones obtained by microdissection of freeze dried material from normal and healing rachitic cartilage of puppies (Hjertquist 1964 b).

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The purpose of the following investigation was to determine whether there were any changes in the organic content of the skeleton and in particular in the glycosaminoglycan and hydroxyproline content of diaphyseal cortical bone during various stages of vitamin D deficiency in young rats.

MATERIAL AND METHODS

Ninety eight male, weanling albino rats of the Sprague Dawley strain with a mean initial body weight of 38.5 gms were used. The animals were allocated at random to two groups, the first of 48 rats was maintained on the test diet[1]) and the second of 50 rats was used as a control group on the test diet supplemented with cod liver oil, 6—7 IU of vitamin D_3 per gm diet. The stock diet contained 1.33 per cent calcium and 0.28 per cent phosphorus. All animals were housed under standard laboratory conditions but without exposure to sun light. The vitamin D deficient rats were given deionized water and the control animals tap water. Food and water were given *ad libitum*. Five to 10 rats from each experimental group were sacrificed at weekly intervals up to 6 weeks. The body weight of the rats was recorded weekly.

After sacrifice by ether the rats were x-rayed. One radius from each was used for histological study (haematoxylin-eosin, toluidine blue and azan stains).

Chemical analysis of the diaphyseal bone: Both humeri and one radius of the rats were dissected free of soft tissue and periosteum. The epiphyses and the metaphyseal parts were removed with a fine band-saw. The diaphyseal cortical cylinders were split and the marrow removed. The bone fragments were then dehydrated for 2 days with several changes of acetone and air-dried. The fragments were crushed and pulverized with a Wiley laboratory mill, using a 60 mesh sieve. Since the amount of bone for the control rats was small and insufficient for individual analyses it was necessary to pool the bones for 6 to 9 rats from each group for chemical analyses.

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[1]) Brunius D-40 diet, composed by ground yellow corn 86, powdered egg albumin 10, calcium carbonate 3 and iodinized NaCl 1 per cent

The total hexosamine content was determined by the Elson and Morgan reaction, as modified by Antonopoulos et al. (1964) and described in detail earlier (Hjertquist and Vejlens, 1968, Larsson and Vejlens 1969). About 4 mg of bone powder were hydrolyzed in 1 ml of 6 M HCl in stoppered test-tubes (Quickfit MF 24/1/5) on a boiling water bath for 8 hours. After evaporation *in vacuo*, over sodium hydroxide pellets, in a dessicator, the residue was dissolved in 0.5 ml distilled water. This solution was used for the determinations. The values were expressed per total dry weight and per organic dry weight, i. e. after correction for the amount of calcium salts present in the acetone dried bone powder as hydroxyapatite.

The hexosamine corresponding to CPC precipitable glycosaminoglycans was determined as described earlier (Hjertquist and Vejlens 1968, Larsson and Vejlens 1969). Briefly about 10 mg bone powder was digested in stoppered test tubes (Quickfit MF 24/1/5) using 3 ml of digestion mixture (0.01—0.05 ml recrystallized papain suspension, Worthington added to 10 ml of a water solution containing EDTA and cystein HCl at a concentration of 0.05 M and 0.005 M, respectively, pH adjusted to 7.0 by 2.0 M NaOH), for 6 hours in a water bath at 65 C. After digestion 2.0 ml 1 % (w/v) cetylpyridinium chloride (CPC) were added to the samples and the mixture was left over night. The precipitate was recovered by centrifugation at 3200 g and hexosamine determinations were performed on the precipitate by the Elson and Morgan reaction described above. The values obtained indicated the CPC precipitable glycosaminoglycans, largely chondroitin sulphate (Hjertquist and Vejlens 1968, Larsson and Vejlens 1969). These values were expressed both per total dry weight and per organic dry weight of the bone powder.

The hydroxyproline was determined on bone powder hydrolysates by the method of Neuman and Logan (1950). The ratios of total hexosamine and the glycosaminoglycans to hydroxyproline were calculated.

Microfractionation of the glycosaminoglycans was performed on pooled acetone dried bone powder from rats on the vitamin D deficient diet for 1 to 5 weeks and from rats maintained on the vitamin D containing diet for 1 to 6 weeks, as described earlier by Larsson and Vejlens (1969). In this was the solubility profiles of the chondroitin sulphate CP-complex and hence information of the molecular weight distribution of this polysaccharide was obtained.

Calcium in bone powder was determined by flame photometry using an ion exchange technique (Dowex $50H^+$, 200—400 mesh), according to the method of Strandh (1960) scaled up; 1.0 mg bone powder was used with 4×20 mm columns, 2.0 ml washing water and 3.0 ml eluting solution (4.0 M HCl).

Because the material for chemical analyses was pooled statistical treatment of the data was not possible. The results are, therefore, recorded as observed differences between mean values. In addition the slopes for the mean values were determined by graphs.

RESULTS

Fourteen deaths occurred during the study, 6 in the treated and 8 in the control group.

The body weight of the rats of both groups remained almost constant up to 3rd week of observation and showed a slight successive increase later (Table I).

Roentgenologic examination of the rats on the vitamin D deficient diet disclosed charasteristic signs of rickets after 3rd week. Rats maintained on the same diet supplemented with vitamin D, showed narrowing of the epiphyseal cartilage, but no other abnormalities.

Histological examination of the distal radial epiphyseal cartilage of the vitamin D deficient rats, showed after 1 week characteristic morphological changes, which were fully developed after 2 to 3 weeks on the diet. The changes were identical to those described in earlier reports on the pathology of vitamin D deficiency in rats, by Dodds and Cameron (1934) and others. The epiphyseal cartilage plates of rats maintained on the vitamin D supplemented diet were normal in appearance except for slight narrowing of width. The diaphyseal cortical bone was extremely thin in both groups of rats. No osteoid seams were found on the examined specimens of cortical bone from vitamin D deficient and control rats.

The total hexosamine concentration per total dry weight of the bone powder was consistently higher for rats maintained on the vitamin D deficient diet, than the corresponding values for the pooled bone powder from the control rats. As the time of observation progressed there was a clear tendency for a decrease in the values in both series (Table I and Fig. 1).

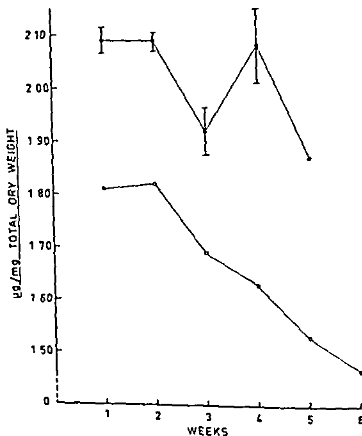


FIG. 1 The total hexosamine content of the cortical bone powder (µg/mg total dry weight) •——• vitamin D deficient rats, o——o control rats. The values for the control rats obtained from pooled material from each group

TABLE I. The chemical composition of diaphyseal cortical bone powder.

	Rats maintained on vitamin D deficient diet						Rats maintained on vitamin D supplemented diet					
	Observation period (weeks)						Observation period (weeks)					
	1	2	3	4	5	6	1	2	3	4	5	6
Body weight gain gms[1])	—2.37	7.85	8.06	22.39	43.21	31.50	3.56	6.00	6.35	14.50	21.50	25.85
	±1.48	±1.70	±1.39	±3.57	±4.64	±4.43	±0.49	±1.75	±2.11	±2.31	±2.17	±3.99
Total hexosamine μg/mg total dry weight	2.09	2.09	1.92	2.08	1.87	—	1.81	1.82	1.69	1.63	1.53	1.47
S. E. M.	±0.026	±0.020	±0.048	±0.068	—	—	—	—	—	—	—	—
n	8	7	8	8	1	—						
Glycosaminoglycans hexosamine μg/mg total dry weight	0.66	0.66	0.67	0.72	0.64	—	0.63	0.61	0.58	0.56	0.53	0.49
S. E. M.	±0.013	±0.016	±0.022	±0.038	—	—						
n	8	7	8	8	1	—						
Total hexosamine μg/mg organic dry weight	4.28	4.38	4.12	4.32	3.90	—	4.02	3.82	3.21	3.35	3.44	2.96
S. E. M	±0.095	±0.048	±0.131	±0.094	—	—						
n	8	7	8	8	1	—						
Glycosaminoglycans hexosamine μg mg organic dry weight	1.36	1.39	1.33	1.50	1.33	—	1.40	1.28	1.10	1.15	1.19	0.99
S. E. M	±0.038	±0.032	±0.040	±0.059	—	—						
n	8	7	8	8	1	—						

Hydroxyproline µg/mg total dry weight	15.2	15.1	14.8	17.1	17.5	—	16.2	17.1	16.4	19.4	—	17.2
S.E.M.	±0.456	±0.614	±0.434	±0.506	—	—						
n	7	5	8	8	1	—						
Hydroxyproline µg/mg organic dry weight	31.9	31.6	31.5	35.9	36.5	—	34.0	35.8	31.0	39.8	—	34.5
S.E.M.	±0.7	±1.5	±1.6	±1.1	—	—						
n	7	5	8	8	1	—						
a) Total hexosamine/Hydroxyproline per total dry weight	0.138	0.138	0.130	0.120	0.107	—	0.112	0.106	0.103	0.084	—	0.085
b) Glycosaminoglycans hexosamine/Hydroxyproline per total dry weight	0.043	0.044	0.042	0.042	0.037	—	0.039	0.036	0.035	0.029	—	0.028
Calcium per cent of total dry weight	20.5	20.9	21.3	20.8	20.8	—	21.8	20.9	18.9	20.5	22.1	20.1
S.E.M.	±0.423	±0.267	±0.666	±0.346	—	—						
n	8	7	8	8	1	—						

[1]) Difference between initial and final body weight

TABLE I. The chemical composition of diaphyseal cortical bone powder.

	Rats maintained on vitamin D deficient diet						Rats maintained on vitamin D supplemented diet					
	Observation period (weeks)						Observation period (weeks)					
	1	2	3	4	5	6	1	2	3	4	5	6
Body weight gain gms[1])	−2.37	7.85	8.06	22.39	43.21	31.50	3.56	6.00	6.35	14.50	21.50	25.85
	±1.48	±1.70	±1.39	±3.57	±4.64	±4.43	±0.49	±1.75	±2.11	±2.31	±2.17	±3.99
Total hexosamine μg/mg total dry weight	2.09	2.09	1.92	2.08	1.87	—	1.81	1.82	1.69	1.63	1.53	1.47
S. E. M.	±0.026	±0.020	±0.048	±0.068	—	—	—	—	—	—	—	—
n	8	7	8	8	1	—						
Glycosaminoglycans hexosamine μg/mg total dry weight	0.66	0.66	0.67	0.72	0.64	—	0.63	0.61	0.58	0.56	0.53	0.49
S. E. M.	±0.013	±0.016	±0.022	±0.038	—	—						
n	8	7	8	8	1	—						
Total hexosamine μg/mg organic dry weight	4.28	4.38	4.12	4.32	3.90	—	4.02	3.82	3.21	3.35	3.44	2.96
S. E. M.	±0.095	±0.048	±0.131	±0.094	—	—						
n	8	7	8	8	1	—						
Glycosaminoglycans hexosamine μg/mg organic dry weight	1.36	1.39	1.33	1.50	1.33	—	1.40	1.28	1.10	1.15	1.19	0.99
S. E. M.	±0.038	±0.032	±0.040	±0.059	—	—						
n	8	7	8	8	1	—						

The hexosamine corresponding to CPC precipitable glycosaminoglycans per total dry weight of the bone powder showed small variations and was almost constant during the period of observation in the vitamin D deficient rats. In rats maintained on the test diet supplemented with vitamin D, there was a slight though definite decrease in the slope during the time of observation and the values were consistently lower than the corresponding values for the vitamin D deficient rats (Table I and Fig. 3).

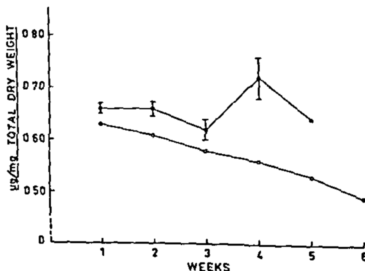


FIG. 3 The glycosaminoglycans hexosamine content of the cortical bone powder (µg/mg total dry weight) •——• vitamin D deficient rats, o——o control rats The values for the control rats obtained from pooled material from each group.

The total hexosamine concentration per organic dry weight of the bone powder from rats maintained on the vitamin D deficient diet were consistently higher than the corresponding values obtained from material pooled from the control rats. There was clear decrease in the slope in the latter case (Table I and Fig. 2).

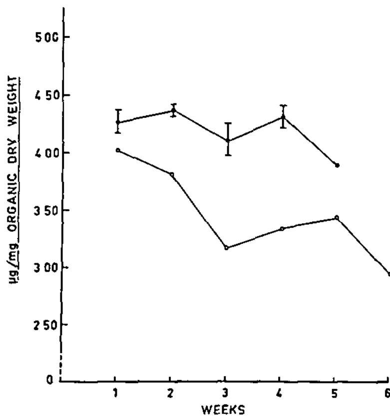


FIG. 2. The total hexosamine content of the cortical bone powder (μg/mg organic dry weight). •——• : vitamin D deficient rats; o——o control rats The values for the control rats obtained from pooled material from each group

The solubility profiles of the CP-complex of the chondroitin sulphate for pooled bone powder from the rats of the 2 experimental groups were remarkably similar. The maximal peak was observed at 0.50 M $MgCl_2$ and the first and last fractions were eluted with 0.25 and 0.75 M $MgCl_2$ respectively in both cases (Fig. 5).

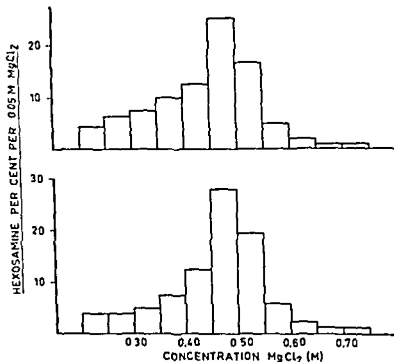


FIG. 5 Solubility profiles of the CP-chondroitin sulphate complexes of the cortical bone powder. Per cent hexosamine per 0.05 M $MgCl_2$ as a function of the concentration of the eluting solution. The amount of hexosamine in expressed as per cent of total hexosamines eluted from the microcolumns. Upper: vitamin D deficient rats. Lower: control rats.

The glycosaminoglycans content per organic dry weight of the bone powder from the vitamin D deficient rats remained almost constant during the period of observation. For the rats maintained on the vitamin D containing diet, the values were consistently lower than the corresponding values for the vitamin D deficient rats, and plotted with time there was a clear decrease in the slope for the mean values (Table I and Fig. 4).

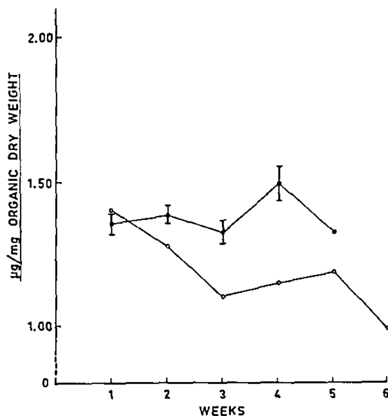


FIG 4. The glycosaminoglycans hexosamine content of the cortical bone powder (µg/mg organic dry weight). •——• vitamin D deficient rats, o——o control rats The values for the control rats obtained from pooled material from each group

The hydroxyproline content per organic dry weight of the bone powder showed also increased values after the 3rd week of observation both for the vitamin D deficient and for the control rats. The values for the vitamin D deficient rats were, with one exception, lower than the corresponding values for the cotnrol rats (Table I and Fig. 7).

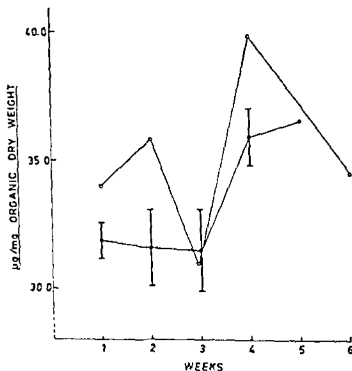


FIG. 7 The hydroxyproline content of the cortical bone powder (µg/mg organic dry weight •——• vitamin D deficient rats, o——o control rats The values for the control rats obtained from pooled material from each group

The hydroxyproline content per total dry weight of the bone powder from rats on the vitamin D deficient diet showed an increase toward the later stage of the experimental period. The values obtained from the vitamin D deficient rats were consistently lower than the corresponding values for the controls (Table I and Fig. 6).

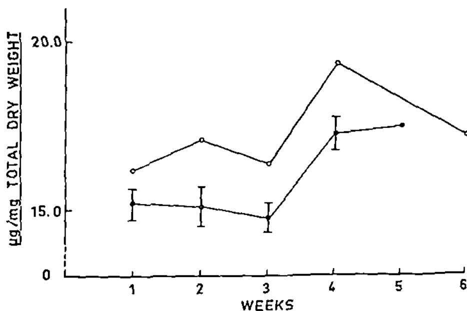


FIG. 6. The hydroxyproline content of the cortical bone powder (µg/mg total dry weight). •——•: vitamin D deficient rats, o——o: control rats. The values for the control rats obtained from pooled material from each group.

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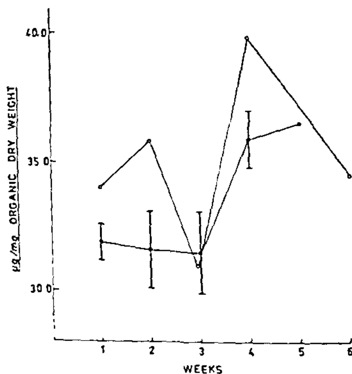


FIG. 7 The hydroxyproline content of the cortical bone powder (μg/mg organic dry weight) •——• vitamin D deficient rats, o——o control rats. The values for the control rats obtained from pooled material from each group

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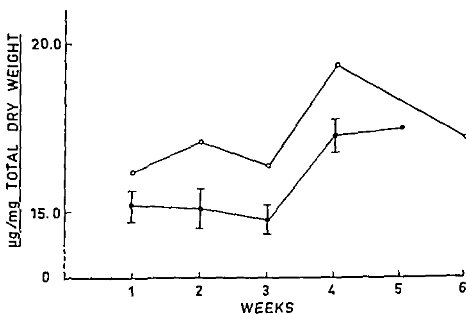


FIG. 6. The hydroxyproline content of the cortical bone powder (µg/mg total dry weight). •——• : vitamin D deficient rats, o——o control rats. The values for the control rats obtained from pooled material from each group.

The calcium content of the bone powder expressed as a fraction of the total dry weight was constant during the period of observation for the vitamin D deficient rats. The calcium content of the bone from the control rats was irregular during the period of observation and showed no consistent tendency when plotted. The observed differences between the corresponding values for the 2 experimental groups were negligeable (Table 1 and Fig. 10).

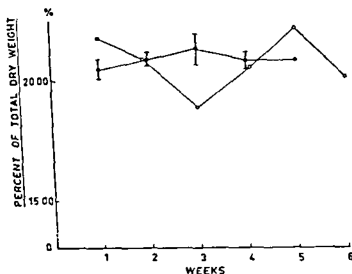


FIG. 10 The calcium content as percentage of the total dry weight of the cortical bone powder •——• *vitamin D deficient rats,* o——o *control rats The values for* the control rats obtained from pooled material from each group

DISCUSSION

Studies of the calcium content of the acetone dried powder derived from cortical bone revealed no appreciable differences between vitamin D deficient rats and rats on the same diet supplemented with adequate amounts of vitamin D

It has been reported that the calcium content of the tibia is lower in rachitic chicks than in controls given the same rachitogenic diet supplemented with vitamin D (Migicovsky and Belanger 1962). The difference between these and the present results might be attributed except that the

The ratios of total hexosamine and glycosaminoglycans to the hydroxyproline content of the cortical bone powder decreased gradually during the experimental period in both groups. This ratio was lower in the vitamin D deficient group at all time intervals (Table I and Figs. 8 and 9).

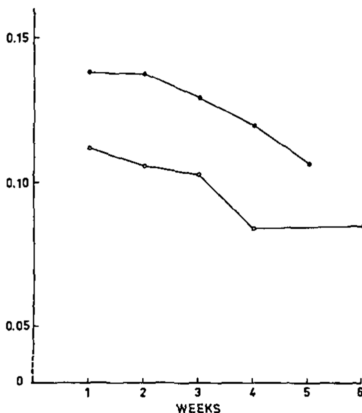


FIG. 8. The ratio total hexosamine/hydroxyproline per total dry weight of the cortical bone powder. •——• : vitamin D deficient rats, o——o : control rats.

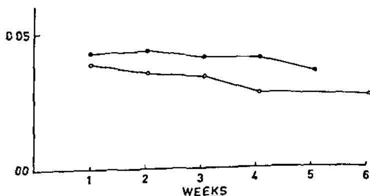


FIG. 9 The ratio glycosaminoglycans hexosamine/hydroxyproline per total dry weight of the cortical bone powder. •——• . vitamin D *deficient rats,* o——o *control rats.*

The calcium content of the bone powder expressed as a fraction of the total dry weight was constant during the period of observation for the vitamin D deficient rats. The calcium content of the bone from the control rats was irregular during the period of observation and showed no consistent tendency when plotted. The observed differences between the corresponding values for the 2 experimental groups were negligeable (Table 1 and Fig. 10).

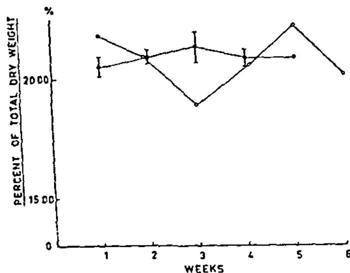


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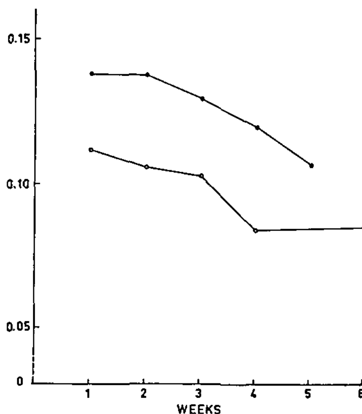


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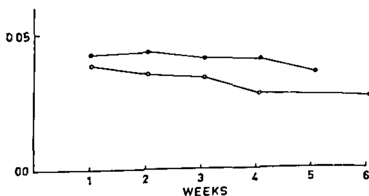


FIG. 9. The ratio glycosaminoglycans hexosamine/hydroxyproline per total dry weight of the cortical bone powder. •——• vitamin D deficient rats, o——o. control rats.

SUMMARY

The glycosaminoglycans, hydroxyproline and calcium content of acetone dried powder of the cortical diaphyseal bone from weanling albino rats maintained for 6 weeks a) on a high calcium, low phosphorus, vitamin D deficient diet and b) on the same diet supplemented with adequate amounts of vitamin D were determined.

The calcium content of the acetone dried cortical bone powder showed no appreciable differences between the two groups.

The hydroxyproline content of the acetone dried bone powder were lower for the vitamin D deficient rats than for the control animals.

The total hexosamine and the glycosaminoglycans hexosamine components were higher in the vitamin D deficient than in the control rats, regardless of whether the fractions were expressed in terms of total dry weight or organic dry weight of the bone powder.

The solubility properties of the chondroitin sulphate of the pooled bone powder from vitamin D deficient and from control rats were remarkably similar, indicating no difference in molecular weight of this polysaccharide.

These results suggest that in rats on a high calcium, low phosphorus diet, vitamin D deficiency leads to a profound change of the organic composition of preformed cortical bone, but not the degree of calcification.

mineral composition of the used diets was different in the two experiments and that animals of different species were used, also to the fact that whole bone and not cortical diaphyseal bone alone was used in the former experiment.

It has also been reported that the calcium content of normal and healing rachitic epiphyseal growth cartilage of dog is higher than that of rachitic animals (Hjertquist 1964 a).

In the light of these observations it seems reasonable to assume that the epiphyseal growth cartilage and the whole bone, including the new-formed metaphyseal cancellous bone, fails to fully calcify when the animals are maintained on a vitamin D deficient diet but that, the calcium content of the previously formed diaphyseal cortical bone remains unchanged, at least during the first 6 weeks on the vitamin D deficient diet. On the other hand the results of this study revealed that the hydroxyproline content of the acetone dried bone powder was lower in vitamin D deficient rats than in control animals. The opposite relation was obtained with the total hexosamine and the glycosaminoglycans hexosamine regardless of whether the results were expressed in term of total dry weight or organic dry weight of the bone powder. Even the ratios of total hexosamine to hydroxyproline and glycosaminoglycans to hydroxyproline were consistently higher in vitamin D deficiency. As mentioned earlier it has been reported that the hexosamine content of the epiphyseal cartilage is decreased (Dikshit 1959) or increased (Cipera et al. 1960) in healing rickets, while no differences were observed as to the glycosaminoglycans content (Hjertquist 1964 a). There have been no previous reports concerning the glycosaminoglycans content of rachitic diaphyseal cortical bone.

The solubility properties of the CP-complex of the chondroitin sulphate of the pooled bone powder from vitamin D deficient rats and from control rats showed no differences, indicating that the molecular weight distribution of the chondroitin sulphate of the cortical diaphyseal bone was essentially the same in the 2 groups of animals.

The results of this study indicate that young rats maintained on a vitamin D deficient diet for up to 6 weeks did not show any changes in the degree of calcification of preformed diaphyseal cortical bone. On the other hand the organic fraction of the bone was profoundly affected with a decrease in hydroxyproline content and an increase in total hexosamine and glycosaminoglycan content. The changes in glycosaminoglycan content of the bone were quantitative and there were no differences in the molecular weight distribution of the chondroitin sulphate.

SUMMARY

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REFERENCES

1. Antonopoulos, C. A., Gardell, S., Szirmai, J. A. and Tyssonsk, E. R.: Biochim. Biophys. Acta, *83:* 1, 1964.
2. Cipera, D., Migicovsky, B. B. and Bélanger, L. F.: Can. J. Biochem. Physiol., *38:* 807, 1960.
3. Dodds, G. S. and Cameron, H. C.: Amer. J. Anat., *55:* 135, 1934.
4. Dikshit, P. K.: Nature, *183:* 334, 1959.
5. Engfeldt, B. and Hjertquist, S.-O.: Wld Rev. Nutr. Diet., *2:* 187, 1960.
6. Follis, R. H.: "Deficiency Diseases", C. C. Thomas Publ., Springfield, Ill., 1958.
7. Follis, R. H.: In "Calcification in Biological Systems", Ed. Sognnaes, R. F. Amer. Ass. Adv. Sci., Washington, D. C., 1960.
8. Fourman, P., Royer, P., Levell, J. M. and Morgan, B. D.: "Calcium Metabolism in the Bone", Blackwell Sci. Publ., Oxford and Edinburgh, 1968.
9. Harris, L. J.: In "The Biochemistry and Physiology of Bone", Ed. Bourne, G. H., Academic Press Inc., N. Y., 1956.
10. Hjertquist, S.-O.: Acta Soc. Med. Upsal., *69:* 83, 1964 a.
11. Hjertquist, S.-O.: Acta Soc. Med. Upsal., *69:* 23, 1964 b.
12. Hjertquist, S.-O. and Vejlens, L.: Calcif. Tiss. Res. *2:* 314, 1968.
13. Irving, J. T.: "Calcium Metabolism", Methuen and Co., Ltd., London, 1957.
14. Larsson, S.-E. and Vejlens, L.: Acta Orthop. Scand., Suppl. no. *120,* 1969.
15. Migicovsky, B. B. and Belanger, L. F.: In "Radioisotopes and Bone", Eds. McLean, F. C., Lacroix, P. and Budy, A. M. Blackwell Sci. Publ., Oxford and Edinburgh, 1962.
16. Neuman, R. E. and Logan, M. A.: J. Biochem., *184:* 299, 1950.
17. Strandh, J. R. E.: Exp. Cell. Res., *21:* 406, 1960.

GENERAL DISCUSSION AND CONCLUSIONS

The relation between vitamin D deficiency and the characteristic morphological changes in growing long bones is well established. Such changes have been induced in dogs (Mellanby 1918, 1919, 1925 and others) in chicks (Wanscher 1939 and others) in rats (McCollum et al. 1921, Sherman and Pappenheimer 1921 and others) as well as in rabbits, guinea pigs, pigs, calves and silver foxes to mention a few (Nicolaysen and Feg-Larsen 1953). The condition induced by vitamin D deficiency in experimental animals correspond to that observed in human rickets to such a degree that it has been stated: "Experimental rickets in animals duplicates completely the spontaneous disease in man and animals" (Wolbach and Bessey 1942). This may be true regarding the morphological changes but it is very doubtful that it is similarly true *with regard to* calcium kinetics, the blood serum changes and bone chemistry. The *results of experimental studies in these respects are controversial and* inconclusive. The divergencies may be attributed to one or more of the following factors, i. e.:

a) the experimental animal,
b) *the duration and degree of the vitamin deficiency,*
c) the composition of the diet, principally with regard to calcium and phosphorus content.

There is a marked difference in species response to the vitamin D (Rasmussen and DeLuca 1963). *It can be assumed, however, that the biochemical role of vitamin D, is the same in all species* (Migicovsky and Belanger 1962). Since the clinical features of *rickets in the dog, chicken* and rat are similar to man (Nicolaysen and Feg-Larsen 1953) and calcium metabolism in rat is similar to man (Nicolaysen and Feg-Larsen 1953, Bronner and Lemaire 1969) it has been assumed that the two systems are comparable. The rat, therefore, has been the animal of choice in experiments on calcium metabolism and hence vitamin D deficiency.

Disagreement in the reported results regarding, for example, effect of parathyroid hormone on mobilization of the bone calcium in the absence of vitamin D in rats, has been attributed to the degree of vitamin deficiency *in the different* experiments (Rasmussen et al. 1963). However, the degree of vitamin D deficiency may not be the only factor responsible for the divergence in results (Sevastikoglou and Ray 1970 c). Maintainance of animals on a vitamin D deficient diet for a sufficiently long period of time is necessary for a clearcut effect, as demonstrated *in the present*

studies. Thus, it was observed that while characteristic morphological changes were present in the growth cartilage plates after 1 week on a vitamin D deficient diet clearcut differences in the chemical composition of the skeleton were not present until the 3rd week (Hjertquist et al. 1970).

Studies of experimental vitamin D deficiency in the rat are further complicated by the fact that this species develops rachitic changes only when the Ca: P ratio of the diet is also modified (Pappenheim and Sherman 1921, Forbes 1967). It has been reported that a disorder simulating rickets can be produced in growing rats by a pure deficiency of phosphorus even in the presence of adequate amounts of vitamin D (Querido 1935, Freeman and McLean 1941, Coleman et al. 1950). It has also been reported that young animals develop skeletal changes typical of rickets upon specific calcium deficiency (Park et al. 1922, Hess 1929, Carttar et al. 1950, Engfeldt et al. 1962, Gershon-Cohen et al. 1962, McClendon and Blaustein 1965). These and other observations have cast doubts on the importance of vitamin D in mineral metabolism of the rat. On the other hand it has been reported that vitamin D is essential for calcium homeostasis in the albino rat even if the animal is fed a diet adequate in calcium and with a suitable ratio of Ca to P (Harrison et al. 1958). It has been stated that calcium and phosphorus content of the diet must be taken into account, in any experiment involving vitamin D deficiency in the rat (Nicolaysen and Eeg-Larsen 1953). It has been further stated that the reaction to vitamin D varies with the mineral composition of the diet (Migicovsky and Emslie 1947) and that in the absence of vitamin D the addition of minerals to the diet results in a rise in the serum Ca and P of the same order as that produced by the vitamin when added to a low mineral diet (Harrand et al. 1966, 1968). By comparison of the effect of diets of different compositions Ray et al. (1956) observed that a low-phosphorus diet displayed the more profound effect on strontium mobilization and skeletal mineralization in young rats These observations and others have led to the statement that "it is necessary to distinguish between vitamin D deficiency and rickets particularly as regards the rat. Although the two are often synonymous they are not always so" (Rasmussen and DeLuca 1963) Thus, standardized dietary conditions are essential in studies of vitamin D deficiency in the rat. It would appear that differences in dietary composition rather than the degree of vitamin D deficiency may account for the differences in results in otherwise similar experiments, a fact already noted by Shelling (1932 a) in studies on the effects of parathyroidectomy in the rat. It is amazing that experimental

reports lack detailed descriptions of the diets, a fact also pointed out earlier (Rasmussen and DeLuca 1963, DeLuca 1967).

In the present experiments young growing rats from two different strains were used, i. e., Long Evans and Sprague Dawley. The rats were of approximately the same age and initial body weights. No special care was taken to obtain animals from strains maintained previously on low vitamin D diets but maintainance of the animals on the vitamin D deficient diet was regarded as sufficiently long, i. e., 3 weeks or more. In spite of the fact that each experiment was carried out with a specific purpose and not as a part of a prospective project, the diets were very similar with only variations related to the nature of the individual study and/or the place where the investigation was carried out. The main features involved in the experimental conditions are summarized in Table I.

TABLE I The main experimental conditions of the present studies.

Exp nr	Strain / Age / Initial body weight		Composition of the diets per dry weight: Ca %	P %	Vitamin D IU/gr diet	Duration of Vitamin D deficiency
1	Sprague Dawley, approx. 5 weeks old, 75 gms		1.40	1.20	Optimal[1])	—
2	Long Evans, a 4 weeks old, 62 gms	I	2.33	0.28	—	Throughout the exp.
		II	0.83	0.28	—	— " —
	b 6 weeks old, 106 gms	III	0.83	0.28	5 IU[2])	—
		IV	2.33	0.28	5 IU	—
3	Sprague Dawley, approx. 5 weeks old, 75 gms	I	1.33	0.28	—	27 days
		II	1.33	0.28	6 IU	—
4	Long Evans, a 4 weeks old, 63 gms	I	2.32	1.48	Optimal[3])	—
	b 3 weeks old, 45 gms	II	2.33	0.28	—	18 days
5	Sprague Dawley, 3 weeks old, 38.5 gms	I	1.33	0.28	—	1—6 weeks
		II	1.33	0.28	6 IU	—

[1]) Standard laboratory ration for rats from Ewos Co., Sodertalje, Sweden. About 15 IU vitamin D/gr diet.

[2]) The necessary amount of vitamin D for the rat depends on the mineral composition of the diet and is about 3 IU/gr diet daily (McCoy 1949).

[3]) Standard laboratory ration for rats from Ralston Purina Co., St. Louis, Miss.

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	a) 4 weeks old 62 gms	II	0 83	0 28	—	— " —
	b 6 weeks old	III	0 83	0 28	5 IU[2]	—
	106 gms	IV	2 33	0 28	5 IU	—
3	Sprague Dawley approx 5 weeks old	I	1 33	0 28	—	27 days
	75 gms	II	1 33	0 28	6 IU	—
4	Long Evans a) 4 weeks old 63 gms	I	2 32	1 48	Optimal[3]	—
	b) 3 weeks old 48 gms	II	2 33	0 28	—	18 days
5	Sprague Dawley 3 weeks old	I	1 33	0 28	—	1—6 weeks
	38.5 gms	II	1 33	0 28	6 IU	—

[1]) Standard laboratory ration for rats from Ewos Co, Södertälje, Sweden About 15 IU vitamin D gr diet

[2]) The necessary amount of vitamin D for the rat depends on the mineral composition of the diet and is about 3 IU gr diet daily (McCoy 1949)

[3]) Standard laboratory ration for rats from Ralston Purina Co., St Louis, Miss. About 14 IU vitamin D gr diet

The experiments were primarily designed to answer the question of whether or not vitamin D has a direct effect on bone metabolism. Possible interrelations between vitamin D and parathyroid hormone were the subject of special studies in this context, although some of the other aspects of the vitamin such as its role in survival and its effect on the chemistry of cortical diaphyseal bone were also studied.

The conclusions drawn from the results of these experiments are discussed in the following pages.

a) THE ACTION OF VITAMIN D ON THE MOBILIZATION OF SKELETAL CALCIUM

As mentioned earlier, several experiments have suggested that there is a relationship between the presence or absence of vitamin D and skeletal calcium turnover. Jones (1930, 1933) in serum calcium determinations on dogs maintained under varying dietary conditions, treated with irradiated ergosterol observed increased serum calcium levels and concluded that the source of the excess serum calcium was the food and not the skeleton. On the other hand, "decalcification" of long bones by large doses of vitamin D was demonstrated by histological techniques (Gyorgy 1930) and it was reported that although therapeutic doses of vitamin D promote calcification of bone, large doses cause bone resorption (Shelling 1932 b). Other experiments on rats, led to the conclusion that vitamin D is apparently not essential for mobilization and transfer of bone calcium to rachitic areas of the skeleton (Jones and Cohn 1936). On the other hand it has also been reported that vitamin D, directly or indirectly may influence the calcification of bone (Nicolaysen and Jansen 1939). These and many other studies indicate that vitamin D probably influences the turnover of skeletal calcium, an effect which, however, has been considered as indirect. In contrast, however, studies of normal and rachitic osteogenetic tissue *in vitro* have shown a clearcut action of vitamin D on calcification (Shipley 1924, Howland 1923, Fischmann 1937). Later it was found that young rat calvaria implanted with crystals of vitamin D into the brains of adult animals underwent pronounced local bone resorption (Barnicott 1951), suggesting a direct effect of large doses of vitamin D on bone calcium metabolism. Evidence for a direct effect of physiological doses of vitamin D on bone resorption was provided by the work of Carlsson and co-workers (1952, 1954, 1955). These observations were confirmed by others (Nicolaysen and Eeg-Larsen 1955). Migicovsky, however, (1957) suggested that vitamin D affects the accretion rate of the bone primarily resulting in a secondary effect on bone resorption. San-

karan (1969) repeated Carlsson's experiment and in addition applied balance and kinetic studies in young rats maintained on a low calcium diet. He observed that the low serum calcium values returned to normal with the addition of vitamin D to the diet. This together with an increase in urinary calcium output and a reduced bone ash content was considered to indicate that vitamin D affected bone resorption. However, it was noted by the author that the experiments were inconclusive as to whether vitamin D had a direct or indirect effect on bone calcium mobilization.

Clinical as well as experimental observations have established that an interaction between vitamin D and parathyroid hormone exists. The observations of Crawford et al. (1957) and Harrison et al. (1958) that the action of parathyroid hormone on mineral mobilization from bone requires the presence of vitamin D, have been confirmed by others (Raoul and Marnay 1960, Rasmussen et al. 1963), thus casting doubt on the suggested direct action of vitamin D on bone metabolism. It has been stated that the effect of vitamin D on bone resorption may be that of permitting the circulating parathyroid hormone to exert its characteristic effect (Rasmussen and DeLuca 1963) and that the action of physiological doses of vitamin D on the skeleton, demonstrated by Carlsson and Lindquist (1955) may not be direct, but mediated through the parathyroid glands (Harrison 1964).

With these facts in mind, the effects of vitamin D in the absence of parathyroid hormone were investigated particularly since this relation had received little attention earlier (Hess et al. 1928/29, Greenwald and Gross 1929, Schelling 1932 b, Asher and Jones 1933) and the results were controversial. Thus, the results of the first investigation showed that *vitamin D in either normal or high levels failed to restore the serum calcium levels of the thyro-parathyroidectomized rats maintained on a diet with normal Ca to P ratio*. This observation was considered to support the view that *vitamin D has no direct action on bone calcium mobilization, its characteristic hypercalcaemic effect taking place through other pathways, probably the parathyroids* (Sevastikoglou and Ray 1970 a).

Since vitamin D involves various physiological target organs in the body, among others the intestine, the parathyroids, the kidneys and possibly bone, it was felt that it would be impossible to determine whether vitamin D has a direct action on bone by *in vivo* experiments, thus the use of *in vitro* experiments were carried out. The studies of Fischmann (1937) regarding calcification of osteogenetic tissue *in vitro* in a medium derived from normal and vitamin D deficient fowl and those

of Goldhaber (1963), Nichols et al. (1963) and Au and Bartter (1966) involving rat or mice bone maintained *in vitro* led to the conclusion that vitamin D has a direct effect on mobilization of bone calcium. However, possible interractions could not be excluded in these experiments because either the media came from natural sources in other words, were not defined or the bone explants were from animals pretreated with vitamin D. It has been showed that minute amounts of parathyroid hormone in a culture medium can result in bone resorption (Gaillard 1965) and also that minute amounts of vitamin D are required for mobilization of bone mineral in response to parathyroid hormone (Rasmussen and DeLuca 1963). It has been reported, on the other hand, that vitamin D fails to stimulate the resorption of bone maintained *in vitro* in a medium containing serum (Raisz 1965).

These observations made it necessary to study the effect of vitamin D on the calcium mobilization *in vitro* system in the absence of parathyroid hormone. The results indicated that *vitamin D had no direct effect either on the uptake nor on the mobilization of calcium from bone derived from vitamin D deficient and normal young rats* (Sevastikoglou and Ray 1970 d).

The results of both experiments indicate that the *action of vitamin D in large or in physiological doses on mobilization of skeletal calcium is dependent on the presence of parathyroid hormone or some related factor.*

b) INTERACTION BETWEEN VITAMIN D AND PARATHYROID HORMONE AND THEIR SIGNIFICANCE FOR THE SURVIVAL OF THE RAT

As mentioned already the results of two of the present experiments led to the conclusion that vitamin D does not have a direct effect on skeletal calcium turnover, (Sevastikoglou and Ray 1970 a and 1970 d). The action of vitamin D has been related to several physiological functions in the body and an interaction between the vitamin and the parathyroids is well documented, although the reported results have not been consistent. Jones (1930) by changing the dietary conditions of parathyroidectomized dogs concluded on the basis of the blood calcium levels that in all probability the antirachitic factor does not act by simply stimulating the parathyroid glands to greater activity. Other experiments indicated that the failure of rachitic animals to respond to parathyroid extract was not directly due to lack of vitamin D (Jones 1935). Blood calcium determinations in vitamin D deficient domestic fowls before and after administration of parathyroid hormone indicated that vitamin D was not necessary

for the action of parathyroid hormone (Hertelendy and Taylor 1960). The same conclusion was drawn from experiments on rats (Toverud 1964) mice (Nichols et al. 1963) and dogs (Ney et al. 1965). On the other hand, experiments on parathyroidectomized and intact rats, under different dietary conditions seemed to indicate that vitamin D and parathyroid hormone had a "synergistic" action on bone metabolism (Crawford et al. 1957). It has been stated that the specific action of parathyroid hormone resulting in mobilization of bone calcium is dependent on the presence of vitamin D or some prior action of it on the target cell (Harrison 1958, Marnay and Raoul 1959, Rasmussen et al. 1963). Harrison and Harrison in 1960 suggested that vitamin D action and the parathyroid hormone effect are probably mutually dependent. Experimental evidence recently provided supported the view that the relation between vitamin D and parathyroid hormone might be based on availability of calcium and not on any direct participation of vitamin D as a co-factor for parathyroid hormone action (Au and Raisz 1967).

Because of the relative confusion and conflicting reports concerning the action of parathyroid hormone on mobilization of bone calcium in the absence of vitamin D a new experiment was carried out. The results showed that young rats maintained for 4 weeks on a high calcium, low phosphorus, vitamin D deficient diet responded with a significant increase in the serum calcium level when given moderate doses (100 IU) of parathyroid extract for 4 consecutive days (Sevastikoglou and Ray 1970 c). This observation led to the conclusion that *while normal levels of parathyroid hormone do not affect the serum calcium level of the vitamin D deficient rat, excess of the hormone results in a rise in serum calcium values*, thus suggesting that *the hypercalcemic effect of parathyroid hormone in large doses is independent of vitamin D.* The results of this experiment were thus in agreement with those of Toverud (1964), Nichols et al (1963) and Ney et al. (1965) but disagreed to the results reported by Harrison et al (1958), Raoul and Marnay (1960) and Rasmussen et al. (1963). The divergence in results was attributed to differences in the composition of the diets rather than to the degree of vitamin D deficiency, as stated previously (Rasmussen et al. 1963).

In spite of divergences concerning the interrelation between parathyroid hormone and vitamin D, it is generally agreed that these substances are primarily responsible for the calcium homeostasis of the body. It seems furher that long term absence of one can be compensated by the other and satisfactory calcium homeostasis effected, the mechanism for this is, however, not known. In the context of the preceeding experiments the

TABLE II. Chemical composition of acetone dried powder from diaphyseal cortical bone from young vitamin D deficient and control rats.

	Rats on vitamin D deficient diet (1—6 weeks).	Rats on diet supplemented with vit. D (1—6 weeks).
Hydroxyproline a) μg/mg acetone dried bone powder	Increased values after the 3rd week on diet, consistently lower than in control rats.	Increased values during the time of observation.
b) μg/mg organic dry weight	Increased values after the 3rd week of observation, lower than in controls.	Irregular slope of the values with a tendency to increase during the time of observation.
Total hexosamine a) μg/mg acetone dried bone powder	Slightly decrease in the slope for mean values after the 2nd week. Consistently higher values than in control rats.	Clearly decrease in the slope for mean values during the period of observation.
b) μg/mg organic dry weight	Same as above, with less pronounced differences from the corresponding values for the control rats.	Same as above.
Glycosaminoglycans-hexosamine a) μg/mg acetone dried bone powder	Values at almost constant or somewhat increasing levels after the 3rd week on diet. Consistently higher values than for the control rats.	Clearly decrease in the slope for mean values during the period of observation.
b) μg/mg organic dry weight	Same as above	Same as above
Solubility properties of glycosaminoglycans	Identical to those of the bone for the control rats.	
Calcium Percentage of the total dry weight	Values at constant level during the period of observation Usually no differences from the corresponding values for the control rats.	Some variations of the values with no slope tendency.

question arose as to whether rats can maintain calcium homeostasis if simultaneously deprived of both vitamin D and parathyroid hormone. Another experiment was undertaken to resolve this question and the results revealed that *4 to 6-week old thyro-parathyroidectomized rats deprived of vitamin D did not survive more than 8 weeks, regardless of whether the calcium intake was adequate or not. If either the parathyroids or vitamin D were present the rats were able to survive even when the calcium intake was very low* (Sevastikoglou and Ray 1970 b). From this study it was concluded that in the *absence of both parathyroid hormone and vitamin D the body is unable to regulate calcium homeostasis either by mobilizing the skeletal calcium reserves or by intestinal absorption of dietary calcium.* Prolonged severe hypocalcaemia, (Sevastikoglou and Ray 1970 c), was probably the cause of the death of the rats.

c) EFFECT OF VITAMIN D DEFICIENCY ON THE CHEMISTRY OF THE DIAPHYSEAL CORTICAL BONE OF THE GROWING RAT

Despite numerous studies of the inorganic component of the skeleton in vitamin D deficiency and some studies of the organic fraction as well, (Dikshit 1959, Cipera et al. 1960, Hjertquist 1964) there are no reports on the chemical composition of cortical bone, especially its organic fraction in rickets. An investigation was, therefore, carried out with this special objective (Hjertquist et al. 1970) the results of which are summarized in Table II

These results led to the conclusion that *in rats on high calcium, low phosphorus diet vitamin D deficiency does not appreciably affect the inorganic component of the preformed cortical diaphyseal bone, but there are profound changes in its organic component including decreased hydroxyproline and increased glycosaminoglycans — principally chondroitin sulphate — contents The molecular weight of this polysaccharide underwent no change* The conclusion has been drawn that the state of calcification of the preformed cortical diaphyseal bone was not influenced by vitamin D deficiency in young rats, or in other words that preformed cortical bone does not reflect the charasteristic changes of rickets, since the condition is primarily a disturbance of the rapidly growing metaphyseal bone This observation is however valid for the species used and the span of time of this experiment.

J. A. S.
R. D. R.

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b) µg/mg organic dry weight	Same as above, with less pronounced differences from the corresponding values for the control rats.	Same as above.
Glycosaminoglycans-hexosamine a) µg/mg acetone dried bone powder	Values at almost constant or somewhat increasing levels after the 3rd week on diet. Consistently higher values than for the control rats.	Clearly decrease in the slope for mean values during the period of observation.
b) µg/mg organic dry weight	Same as above.	Same as above.
Solubility properties of glycosaminoglycans	Identical to those of the bone for the control rats.	
Calcium Percentage of the total dry weight	Values at constant level during the period of observation. Usually no differences from the corresponding values for the control rats.	Some variations of the values with no slope tendency.

32. Fourman, P, Royer, P, Levell, M. J. and Morgan, B D: Calcium Metabolism and the Bone. Blackwell Scientific Publications, Oxford and Edinburgh, 1968.
33. Frederich, A.: Path. et Biol., Sem Hôp. Paris (n.s) 13: 434, 1965.
34. Freeman, S and McLean, F. C.: Arch. Path, 32: 387, 1941.
35. Funk, C.: J Physiol, 45: 75, 1912.
36. Gaillard, P. J: Exp Cell Res, Suppl. no 3, 1955
37. Gaillard, P. J. Schweiz. Med Wschr, 87. 447, 1957.
38. Gaillard, P. J: In "The Parathyroid Glands". Eds. Gaillard, P. J, Talmage, R. V. and Budy, A M. The University of Chicago Press, Chicago and London, 1965.
39. Gershon Cohen, J, McClendon, J F., Jowsey, J and Foster, W. C.: Radiology, 78 251, 1962
40. Glison, F.: "De Rachitide", London, 1650
41. Goldhaber, P.: In "Mechanism of Hard Tissue Destruction", p. 609. Ed. Sognnaes, R F., Am Ass Adv Sci, Washington, D. C., 1963.
42. Gran, F C. Acta Physiol Scand, 49 211, 1960
43. Greenvald, I and Gross, J J Biol Chem, 82 505, 1929
44. Greep, R O and Kenny, A. D. In "The Hormones". Vol. no 3, Chapt. 4. Eds. Pincus, ? ?. and Thimann, ? ? Academic Press Inc., N. Y., 1965
45. Grollman, A Endocrinology, 55 166, 1954
46. Guérin, J Gaz Med. (Paris), 6 332, 1838.
47. Gyorgy, P Klin Wschr, 9 102, 1930.
48. Harrand, R B, Green, R. M and Hartles, R. L. Br J Nutr., 20 55, 1966
49. Harrand, R B and Hartles, R. L. Br J Nutr, 22: 45, 1968.
50. Harris, L. J Sci Progr, 23 68, 1928
51. Harris, L J and Innes, J R M Biochem J, 25 367, 1931.
52. Harris, L J Lancet i 1031, 1932
53. Harris, L J In "The Biochemistry and Physiology of Bone" Ed Bourne, G H Academic Press Inc, N Y, 1956
54. Harrison, H E and Harrison, H. C J Clin Invest, 20 47, 1941.
55. Harrison, H E and Harrison, H C Yale J. Biol Med., 24 273, 1952.
56. Harrison, H C, Harrison, H E and Park, E. A Amer. J Physiol, 192 432, 1958
57. Harrison, H F and Harrison, H C In "Bone as a Tissue". Eds. Rodahl, H., Nicholson, J T and Brown, E M., McGraw-Hill, Eds, New York, 1960.
58. Harrison, H E Yale J Biol Med, 38 393, 1966
59. Harrison, M T Postgrad Med J, 40 497, 1964
60. Hertelendy, F and Taylor, T G Biochim. Biophys Acta, 44 200, 1960.
61. Hess A F and Weinstock, W. J Biol Chem, 62 301, 1924.
62. Hess, A F, Weinstock, M and Rivkin, H Proc Soc. Exp. Biol (N. Y.), 26: 555, 1928/29
63. Hess, A F "Rickets, including osteomalacia and tetany". Lea and Febiger, Philadelphia, 1929
64. Hjertquist, S O Acta Soc Med Upsal., 69 23, 1964
65. Hjertquist, S O, Bergquist, E. and Sevastikoglou, J A.. Acta Orthop Scand, Suppl no 136, 1970
66. Hopkins, F G J Physiol, 44 425, 1912.
67. Howland, J Medicine (Baltimore), 2 349, 1923
68. Huldschinsky, S Dtsch Med. Wochschr., 45 712, 1919

REFERENCES

1. Albright, F.: J. Clin. Endocr., *8:* 637, 1948.
2. Asher, D. W. and Jones, J. H.: J. Biol. Chem., *100:* 333, 1933.
3. Askew, F. A., Bourdillon, R. B., Bruce, H. M., Jenkins, R. G. C. and Webster, T. A.: Proc. Roy. Soc., *B-107*, 76, 1930.
4. Au, W. Y. W. and Bartter, F. C.: Endocrinology *78.* 1100, 1966.
5. Au, W. Y. W. and Raisz, L. G.: J. Clin. Invest., *46:* 1572, 1967.
6. Barnicott, N. A.: J. Anat., *82:* 232, 1948.
7. Barnicott, N. A.: J. Anat., *85:* 120, 1951.
8. Bronner, F.: Amer. J. Physiol., *198:* 605, 1960.
9. Bronner, F. and Lemaire, R.: Calcif. Tiss. Res, *3:* 238, 1969.
10. Carlsson, A.: Acta Physiol. Scand., *26*· 212, 1952.
11. Carlsson, A.· Acta Physiol. Scand., *31*· 301, 1954.
12. Carlsson, A. and Hollunger, G.: Acta Physiol. Scand., *31* 317, 1954.
13. Carlsson, A. and Lindquist, B.. Acta Physiol. Scand, *35:* 53, 1955.
14. Carttar, M. S., McLean, F. C. and Urist, M. R.: Amer. J. Path., *26*· 307, 1950.
15. Chang, H. Y.: Anat. Rec., *111:* 23, 1951.
16. Cipera, J. D., Migicovsky, B. B. and Bélanger, L. F.· Canad. J. Biochem. Physiol, *38*· 807, 1960.
17. Coleman, R D., Becks, H., Kohl, F V. N. and Copp, D H.. A. M. A. Arch. Path, *50* 209, 1950.
18. Crawford, J. D, Gribetz, D., Diner, W. C, Hurst, P and Castleman, B.: Endocrinology, *61.* 59, 1957.
19. DeLuca, H. F., Engstrom, G. W. and Rasmussen, H. Proc. Nat. Acad. Sci, *48*· 1604, 1962
20. DeLuca, H. F.: Vitam. and Horm, *25* 315, 1967.
21. DeLuca, H. F.: Fed. Proc., *28.* 1678, 1969
22 Dikshit, P. K.: Nature, *183* 334, 1959.
23. Dodds, G S. and Cameron, H. C. Amer. J Anat, *55* 135, 1934
24. Dodds, G. S and Cameron, H C.· Amer J Path., *14* 273, 1938
25. Dowdle, E B, Schachter, D and Schenker, H Amer J Physiol, *198* 269, 1960.
26. Engfeldt, B, Hjertquist, S-O and Lagergren, C Acta Soc. Med. Upsal., *67* 239, 1962
27. Engstrom, G W and DeLuca, H F J Biol Chem, *237* 974, 1962
28 Engstrom, G W and DeLuca, H F Biochem, *3* 303, 1964
29 Firschein, H E J Chron Dis, *16* 283, 1963.
30 Fischmann, ? ? Arch exp Zellforsch, *19* 211, 1937
31 Forbes, G B· Nutr Rev., *25* 225, 1967

32. *Fourman, P.*, Royer, P., Levell, M. J. and Morgan, B. D: Calcium Metabolism and the Bone Blackwell Scientific Publications, Oxford and Edinburgh, 1968.
33. Frederich, A · Path. et Biol, Sem. Hôp, Paris (n. s) *13*·434, *1965*.
34. Freeman, S. and McLean, F. C: Arch Path, 32 387, 1941.
35. Funk, C.: J. Physiol, *45*·75, 1912.
36 Gaillard, P. J · Exp Cell. Res, Suppl. no. 3, 1955.
37. Gaillard, P. J: Schweiz. Med. Wschr, 87. 447, 1957.
38. Gaillard, P. J: *In "The Parathyroid Glands". Eds. Gaillard, P. J.*, Talmage, R. V. and Budy, A M. The University of Chicago Press, Chicago and London, 1965.
39 Gershon Cohen, J., McClendon, J F, Jowsey, J. and Foster, W. C.: Radiology, *78*·251, 1962.
40 Glison, F. "De Rachitide", London, 1650.
41 *Goldhaber, P · In "Mechanism of Hard Tissue Destruction", p* 609. Ed. Sognnaes, R. F, Am Ass. Adv Sci, Washington, D C, 1963.
42 Gran, F C Acta Physiol Scand., *49* 211, *1960*
43 Greenvald, I and Gross, J J Biol. Chem, *82* 505, 1929.
44 Greep, R. O and Kenny, A D. In "The Hormones". Vol. no. 3, Chapt 4. Eds. *Pincus, › › and Thimann, ›. ›* Academic Press Inc, N. Y, *1965*.
45 Grollman, A. Endocrinology, *55* 166, 1954
46 Guerin, J Gaz. Med. (Paris), *6 332, 1838*
47 Gyorgy, P Klin Wschr, 9 102, 1930
48 Harrand, R B, Green, R. M and Hartles, R. L· Br J Nutr., *20*·55, 1966
49 Harrand, R B and Hartles, R L. Br J Nutr, 22 45, 1968.
50 Harris, L. J Sci Progr, 23 68, 1928
51 *Harris, L J and Innes, J R M Biochem J, 25:367, 1931.*
52 Harris, L. J Lancet ı 1031, 1932
53 Harris, L J In "The Biochemistry and Physiology of Bone". Ed. Bourne, G. H. Academic Press Inc, N Y, 1956
54. Harrison, H E and Harrison, H C. J Clin Invest, *20* 47, 1941.
55 Harrison, H E. and Harrison, H C Yale *J* Biol. *Med*, *24* 273, *1952*.
56 Harrison, H C, Harrison, H E and Park, E A: Amer J Physiol, *192:*432, *1958*
57 Harrison, H F and Harrison, H C In "Bone as a Tissue" Eds. Rodahl, H, Nicholson, J T and Brown, E. M, McGraw-Hill, Eds., New York, 1960.
58 Harrison, H E. Yale J Biol Med, *38* 393, 1966.
59 Harrison, M T Postgrad Med J, *40* 497, 1964
60 Hertelendy, F and Taylor, T. G Biochim *Biophys Acta, 44 200, 1960.*
61 Hess, A F and Weinstock, W J Biol Chem, 62 301, 1924
62 Hess, A F, Weinstock, M and Rivkin, H Proc Soc Exp Biol (N. Y.), *26* 555, 1928/29
63 Hess, A F "Rickets, including osteomalacia and tetany". Lea and Febiger, Philadelphia, 1929
64 Hjertquist, S O Acta Soc Med Upsal., 69 23, *1964*
65 Hjertquist, S O, Bergquist, E *and* Sevastikoglou, J A Acta Orthop Scand, Suppl no 136, 1970
66 Hopkins, F G J *Physiol*, *44* 425, 1912
67 Howland, J Medicine (Baltimore), 2 349, 1923
68 Huldschinsky, S Dtsch Med Wochschr, *45* 712, 1919

69. Jones, J. H.: J. Biol. Chem., *100:* 343, *1933.*
70. Jones, J. H.: J. Biol. Chem., *106:* 701, *1935.*
71. Jones, J. H. and Cohn, B. N. E.: J. Nutr., *11:* 293, *1936.*
72. Marnay, C. and Raoul, Y.: C. R. Soc. Biol. (Paris), *153:* 1949, 1959.
73. Marnay, C.: J. Physiol. (Paris), *53:* 423, 1961.
74. McClendon, J. F. and Blaustein, A.: Nature, *2:* 95, 1965.
75. McCoy, R. H.: In "The Rat in Laboratory investigation". Eds. Farris, E. J. and Griffith, J. Q., Hafner Publ. Co., New York, 1949.
76. McLean, F. C. and Bloom, W.: Arch. Pathol, *32:* 315, 1941.
77. McLean, F. C. and Urist, M. R.: Bone. An Introduction to the Physiology of the Skeletal Tissue. The University of Chicago Press, Chicago, Ill., 1955.
78. McCollum, E. V., Simmonds, N. and Parsons, H. T.: J. Biol. Chem., *45:* 333, 1921.
79. Mellanby, E.: J. Physiol. Proc. Physiol. Soc. XI—XII, *52,* 1919.
80. Mellanby, E.: Lancet, *196* 407, 1919.
81. Mellanby, E.: Rep. Med. Res. Coun. (London), *93, 1925.*
82. Migicovsky, B. B. and Emslie, A. R. G.: Arch. Biochem., *13:* 175, *1947.*
83. Migicovsky, B. B. and Bélanger, L. F.: In "Radioisotopes and Bone". Eds. McLean, F. C., Lacroix, P. and Budy, A. M. Blackwell Scientific Publications, Oxford, *1962.*
84. Migicovsky, B. B.: Canad. J. Biochem. Physiol., *35:* 1267, *1957.*
85. Neuman, W. F. and Neuman, M. W.: "Chemical Dynamics of Bone Mineral". University of Chicago Press, Chicago, Ill., *1958.*
86. Ney, R. L., Au, W. Y. W., Kelly, G., Radde, I. and Bartter, F. C.: J Clin. Invest., *44* 2003, 1965.
87. Nichols, G., Schartum, S. and Vaes, G. M.: Acta Physiol. Scand., *57:* 51, *1963.*
88. Nicolaysen, R.: Skand Arch. Physiol., *69,* Suppl. 1—*66, 1934.*
89. Nicolaysen, R.: Biochem. J., *31* 107, *1937.*
90. Nicolaysen, R. and Jansen, J. Acta Paediat., *23:* 405, *1939.*
91. Nicolaysen, R and Eeg-Larsen, N.. Vitam. and Horm., *11:* 29, *1953.*
92. Norman, A. W. Amer. J. Physiol, *211:* 829, *1966.*
93 Norman, A. W.: Biol. Rev., *43.* 97, *1968.*
94. Park, E. A., Shipley, P. G, McCollum, E. V. and Simmonds, N. Proc. Soc. Exp Biol. (N. Y.), *19:* 149, 1922.
95. Querido, A. Arch. Neerl. Physiol., *20* 487, 1935
96. Raisz, L. G., Au, W. Y. W. and Tepperman, J.: Endocrinology, *68* 783, *1961*
97. Raisz, L. G.. J. Clin. Invest, *44* 103, 1965.
98. Raoul, Y. and Marnay, C. Acta Endocr., Suppl. no. 51, p 485, 1960
99. Rasmussen, H, DeLuca, H. F, Arnaud, C, Hawker, C. and v. Stedingk, M J. Clin Invest., 42 1940, 1963
100 Rasmussen, H and DeLuca, H F Ergebn Physiol, *53* 108, *1963*
101. Ray, R. D, Stedman, D F and Wolff, N K J. Bone Jt Surg, *38-A* 637, *1956.*
102. Sandaran, B Personal communication, 1969
103. Schachter, D. and Rosen, S M. Amer J Physiol, *196* 357, *1959*
104 Schelling, D. H J Biol. Chem, *96* 195, *1932 a*
105. Schelling, D. H J Biol. Chem., *96* 215, *1932 a*
106. Scherman, H C and Pappenheimer, A. M.. Proc Soc. Exp Biol (N Y), *18 193,* 1921.
107. Schneider, H. and Steenbock, H. J Urol., *43 159, 1939*
108. Sevastikoglou, J. A. and Ray, R. D.: Acta Orthop. Scand., Suppl no. *136, 1970 a*

109. Sevastikoglou, J A. and Ray, R. D.: Acta Orthop Scand., Suppl. no. 136, 1970 b.
110. Sevastikoglou, J A. and Ray, R. D · Acta Orthop. Scand., Suppl. no. 136, 1970 c.
111. Sevastikoglou, J. A. and Ray, R. D.: Acta Orthop. Scand., Suppl. no. 136, 1970 d.
112. Shipley, P. G · Bull. Johns Hopk. Hosp, 35·304, 1924.
113. Steenbock, H.: Science, 60 224, 1924.
114. Talmage, R. V. and Elliot, J R.: Endocrinology, 62: 717, 1958.
115. Toverud, S. U.: Acta Physiol Scand, 62·391, 1964.
116. Trousseau, A.: "Clinique Médicale de l'Hôtel Dieu de Paris". Ed. Baillière, Paris, 1865.
117. Wanscher, O: Thesis, Copenhagen, A. Bush Forlag, 1939.
118. Wasserman, R. H "The transfer of calcium and strontium across biological membranes". Academic Press Inc., N. Y., 1963.
119. Wasserman, R. H. and Taylor, A N. Science, 152: 791, 1966.
120. Watanabee, T · Biol Abstr, no 23767, 1960
121. Weinman, J. P. and Sicher, H "Bone and Bones. Fundamentals of bone biology". 2nd ed, Henry Kimpton, London, 1955
122. Whistler, D. De Morbo puerili Anglorum quem patrio idiomate indigenae vocant. The Rickets, Thesis, Leyden, 1645.
123. Windhous, A, Linsert, O, Lutteringhaus, A and Weidlich, G · Ann. Chim 492· 226, 1932.
124. Wolbach, S. B and Bessey, O A Physiol. Rev, 22 233, 1942.
125. Woods, K. R and Armstrong, W D Proc. Soc. Exp. Biol. Med., 91·255, 1956.
126. Yuile, C L., Chen, P. S and Bossman, H. B: Arch. Pathol, 83. 241, 1967.
127. Zetterstrom, R Studies on the mode of action of vitamin D. Thesis. Stockholm, 1951.

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A Mechanical Method

Tryckeriaktiebolaget City

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by

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Contents

I. Introduction

Whether and to what extent union of a fracture is taking place is reflected in the stability of the fracture. To determine whether this has increased over a given period is, however, by no means a simple matter, especially in the case of delayed union, but it would seem that an objective measure of the stability is provided by the degree to which the fracture is deflected under a load. To devise a method for following the development of stability by measuring this deflection at intervals was the object of the investigation reported in this monograph.

In principle, the deflection of the fractured bone is recorded as a function of the applied bending force, and an instrument has been designed by means of which such a registration can be made. The reliability of the instrument has been determined experimentally on autopsy specimens of the tibia, and the suitability of the method for clinical use has been examined by performing measurements on patients.

The deflection of a bone produced by the application of a load is dependent on its modulus of elasticity. This quantity, which affords a basis for comparison of the stiffness of bones, can be calculated from the deflection of the bone and the moment of inertia of its cross section. As no picture of the section can be obtained in the living subject a formula has been derived that provides an approximate value of the moment of inertia of this area. The required dimensions of the cross section are determined from radiographs taken with known projections.

Thus, from the deflection of the bone and the moment of inertia a rough measure of the stability of the fracture can be obtained. The total deflection of the bone is composed of the deflection of the bone fragments and that within the actual fracture. The former component is obtained from measurements on the other, sound, tibia, and by subtracting this from the total deflection, the deflection within the actual fracture is obtained, and hence the flexural rigidity of the fracture callus can be determined. This rigidity reflects the stage of healing and hence indicates when the various steps of treatment should be introduced—for example, when it is safe to permit normal functional loading of the leg.

from calculated directions of the principal central axes. From photographic enlargements of the cross section of a bone Mather (1967) calculated its moment of inertia by a graphical method devised by Mohr (Andrews, 1934). Knese *et al.* (1956) determined the moment of inertia and the directions of the principal central axes of bone specimens by means of an integrator, as did Comtet *et al.* (1967).

The elasticity and strength of bone vary according to the type of deforming force and also according to the relative position of the longitudinal axis of the test specimen and axis of the bone. The elasticity and strength are least in the transverse direction and greatest parallel to the axis (Olivo *et al.*, 1937; Dempster & Liddicoat, 1952; Dempster & Coleman, 1961; Sedlin, 1965, Sedlin & Hirsch, 1966; Hirsch & da Silva, 1967; Blaimont, 1968; Lang, 1969). This is due to the largely axial orientation of the collagen fibres; these have a high tensile strength and modulus of elasticity for axial tension. Apatite, whose crystals are oriented with their longitudinal axes parallel to the collagen fibrils, has a low tensile but high compressive strength, and a higher modulus of elasticity for axial compression (Glimcher, 1959; Molnar, 1960; Currey, 1964; Sweeney *et al.*, 1965).

According to three current theories on the combined function of the collagen and the apatite these components can act as a compound bar, the collagen fibres can be pre-stressed so that the bone behaves as a prestressed material (Knese, 1958), or the bone can constitute a two-phase material similar to fibre glass (Currey, 1964; Mack, 1964).

The modulus of elasticity is slightly higher for tension than compression. When a bone is bent the stress and strain are compressive on the concave side and tensile on the convex, and the modulus of elasticity in bending will be a resultant of the values for compression and tension. There is a close relationship between the maximum bending strength and the modulus of elasticity in bending, which is the parameter that can be used in clinical work for comparing different vital bones (Weir *et al.*, 1949; Smith & Walmsley, 1959, Sedlin & Hirsch, 1966; Mather, 1967).

Values of the modulus of elasticity in bending that have been reported for the human tibia include $(0.81—1.42)\times10^3$ (Smith & Walmsley, 1959), 1.22×10^3 (Motoshima, 1960), $(1.4—2.6)\times10^3$ (Rabischong, 1965), and 1.44×10^3 kgf/mm² (Mather, 1967); and for the femur, $(1.06—1.97)\times10^3$ (Sedlin & Hirsch, 1966), and 1.36×10^3 kgf/mm² (Mather, 1967).

II. *Physical properties of bone*

Since Wertheim's studies published in 1847 the physical properties of bone have been a subject of increasing interest, and many of them have been elucidated in reviews published in recent years (Evans 1957, 1966; Knese 1958; Blaimont 1968).

Bone being a heterogeneous anisotropic substance with varying structure, the determination of its deformation and moment of inertia presents considerable difficulty; but neither of these properties need be known for the ultimate strength to be found. In tension and compression the stress is distributed uniformly over the cross sectional area and if tensile and compressive tests can be used to obtain values for the required mechanical properties of the bone, a knowledge of the moment of inertia is unnecessary; but if bending or torsional tests are used, this moment must be known, because, like the modulus of elasticity or rigidity, it is a critical quantity for the magnitude of the deflection or torsion.

If test specimens can be used instead of large pieces or intact bones, the moment of inertia can be accurately calculated from the cross section. Most studies of the mechanical properties of bone have been performed on such test specimens (Olivo *et al.*, 1937; Carothers *et al.*, 1949; Dempster & Liddicoat, 1952; Evans, 1957; Dempster & Coleman, 1961; Vose, 1962; McElhaney, 1964; Sedlin, 1965; Sweeney *et al.*, 1965; Sedlin & Hirsch, 1966; Lindahl & Lindgren, 1967). Where large pieces of bone or intact bones have been used, it has been values for the properties in tension or compression or for the ultimate strength that have been determined; otherwise the moment of inertia of the section must have been calculated.

In determinations of the moment of inertia the cross section of the bone has been taken as circular or elliptical (Grunewald, 1920; Bell *et al.*, 1941; Weir *et al.*, 1949; Vose & Kubala, 1961; Currey, 1969). A numerical integration of the moment (see page 33) after balancing the centre of gravity has been performed and the principal central axes have been inserted by inspection (Koch, 1917). Blaimont (1968) has determined the moment of inertia in a like manner after finding the direction of the axes experimentally. By graphic integration Marique (1945) found the moment of inertia

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and where φ is the required angle between one principal central axis of the tibia section and the axis of x. I_{45° and I_{135° are the moments of inertia about the axes of a coordinate system having the origin in the centroid but rotated through 45° in relation to the coordinate system xy.

The principal moments of inertia of the tibia section are given by the formula:

$$\begin{matrix} I_{max} \\ I_{min} \end{matrix} = \frac{1}{2}\left\{ (I_x+I_y) \pm \left[(I_x-I_y)^2 + (I_{135^\circ}-I_{45^\circ})^2 \right]^{1/2} \right\} \quad \ldots \quad [4]$$

If the central axis is rotated through an angle φ about the centroid in the plane of section the moment of inertia will change to:

$$I\varphi = I_{min}\cos^2\varphi + I_{max}\sin^2\varphi \quad \ldots \quad [5]$$

Its magnitude is thus dependent on the angle φ and the magnitude of I_{min} and I_{max}.

The maximum deflection of a simple beam freely supported at the ends and loaded at its midpoint is obtained when the force acts against the minimum moment of inertia, that is to say, in the bending plane with respect to the minimum moment of inertia. If the line of action of the bending force P (Fig. 1) applied to the tibia, regarded as a simple beam,

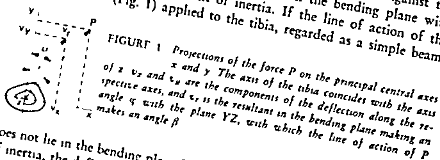


FIGURE 1 *Projections of the force P on the principal central axes x and y. The axis of the tibia coincides with the axis of z. v_x and v_y are the components of the deflection along the respective axes, and v_r is the resultant in the bending plane making an angle φ with the plane YZ, with which the line of action of P makes an angle β*

does not lie in the bending plane YZ with respect to the minimum moment of inertia, the deflection will occur in the direction of a resultant v_r whose components v_x and v_y coincide with the axes x, y, the principal axes of the tibia section.

If the line of action of the force P makes an angle β with the plane YZ, one component of the force, $P \sin\beta$, acts along the axis of x, and the other, $P\cos\beta$, acts along the axis of y. The components of the deflection are thus $v_x = PL^3 \sin\beta / 48\, EI_{max}$, and $v_y = PL^3\cos\beta/48\, EI_{min}$. The resultant v_r will act in a bending plane making an angle φ with the bending plane YZ, where

$$\tan\varphi = I_{min}\tan\beta / I_{max} \quad \ldots \quad [6]$$

The magnitude of the total deflection v_r can be calculated from v_x and v_y by application of the Theorem of Pythagoras. The quantity recorded,

III. *Notation and formulae*

The following notation has been adopted in this monograph.

σ Stress
ε Strain
v Deflection recorded under load
δ Corrected deflection
E Young's modulus of elasticity
I Moment of inertia
L Length, span
M Bending moment
P Concentrated load
a Diameter of marrow space
b Breadth of section of the tibia
d Thickness of section of the tibia
l Distance from nearer outer pin to fracture

FORMULAE

The derivations of the formulae used in this study are to be found in the usual reference books of mechanics (Andrews, 1934; Baumeister & Marks, 1958). In the following theoretical analysis of the deflection of the tibia it is assumed that bone is an ideal elastic material.

The application of a force to an elastic material produces a stress σ that is proportional to the strain ε in accordance with Hooke's law:

$$\sigma = E\,\varepsilon \qquad [1]$$

where E, the modulus of elasticity, is a constant that is valid below the limit of proportionality. It can be calculated from the expression for the deflection of a uniform straight beam freely supported at both ends and subjected to a load at its midpoint. The formula, which is based on Mohr's theorem, is

$$\delta = PL^3/48\,EI \qquad [2]$$

All the values of the modulus of elasticity stated in this report refer to bending.

The positions of the principal central axes are obtained from the equation:

$$\tan 2\,\varphi = (I_{135^\circ} - I_{45^\circ})/(I_y - I_x) \qquad [3]$$

where I_x and I_y are the moments of inertia of the tibia section about the axes of a rectangular coordinate system xy with the origin in the centroid,

and where q is the required angle between one principal central axis of the tibia section and the axis of x. $I_{\xi\eta}$ and $I_{\xi\eta\eta}$ are the moments of inertia about the axes of a coordinate system having the origin in the centroid but rotated through 45° in relation to the coordinate system xy.

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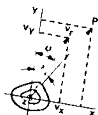


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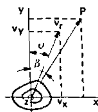


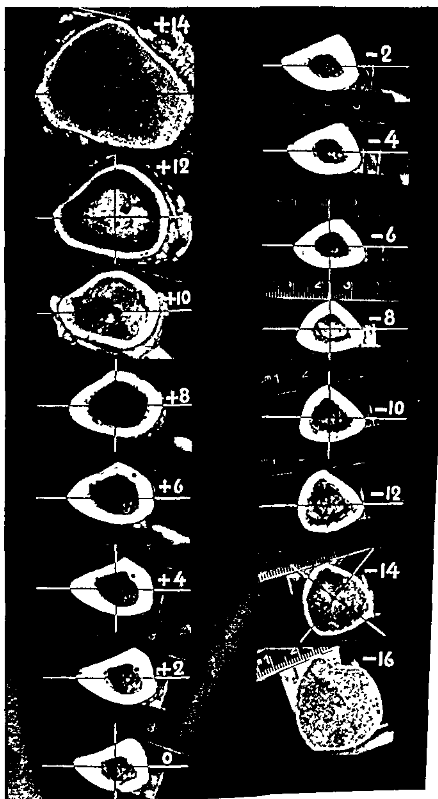
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+14
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
-12
-14
-16

minimum moment of inertia of the cross sections of 5 tibias are shown at the top of figure 4. For one of the bones the moment was determined by means of integrator, and for the other by numerical integration. The minimum moment of inertia of the tibia I_{min} and that of each section $I_{min(x)}$ is placed on the axis of ordinates and is plotted as a function of the length of the tibia. Thus, the curve for each bone shows the variation of I_{min} along the tibia. From the values in each curve the deflection curve for each specimen was calculated by means of a computer. At the bottom of figure 4 one such curve—for specimen 2, left tibia—is compared with that which would be obtained if the tibia were a straight uniform beam. At the same time as the curves were computed the value of the constant in eqn. [2] was obtained for each of the five bones and the two loading systems with the supporting pins 21 and 24 cm apart (see page 19). As regards the minimum moment of inertia for the smallest cross section, the constant in the formula for the deflection of the tibia will be 1/66 and 1/67, respectively. The standard deviation of the constants for the five bones is 5 per cent. The expressions for the deflection of the tibia are thus:

$$\delta_{21} = 21^3 P/66\ EI_{min} \qquad \delta_{24} = 24^3 P/67\ EI_{min} \qquad \ldots \quad \ldots \quad [9]$$

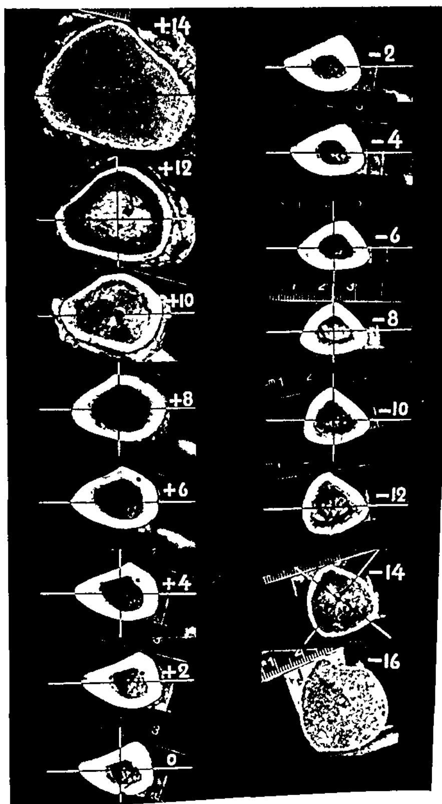
The original eqn. [2] was used in the subsequent calculations for determining E, and the values of the modulus of elasticity so obtained are designated the apparent modulus of elasticity, "E", while the values yielded by eqn. [9] are given below together with the magnitude of the constant.

DEFLECTION OF THE CALLUS

Fracture callus may be regarded as a visco-elastic material. During the course of the union the viscous component diminishes and the elasticity of the callus increases until it is ultimately the same as for the rest of the bone. This may be checked by measuring the distance between the rising and descending part of the load-deflection curve when the applied force is zero.

A true model for the deflection of the callus would thus require the application of advanced plastic theory, in which the viscous and elastic component are functions of the time. Account would also need to be taken

FIGURE 3 *Cross sections taken from 14 cm proximally (+) to 16 cm distally (—) of the midpoint (0) of a tibia specimen The intersecting lines are the principal central axes of the moment of inertia, whose positions were determined by means of an integrator A single line through the section marks the direction of the principal central axis of the minimum moment of inertia, which was inserted by inspection*


+14
+12
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
-12
-14
-16

as a spring joint, a joint which can take up a bending moment, and later as a very short beam, where the viscous component and shear are neglected. This approach is necessary in order to obtain a conception of the physical properties of the callus.

In the model, the fractured bone is regarded as two beams connected by a spring joint; the applied bending moment of the spring joint is given by the expression $M = C\alpha$, where C is the spring constant and α the angulation of the spring joint. The total deflection of the model δ_{tot} is the sum of the deflections of the beams δ_t and the spring joint δ_f, that is,

$$\delta_{tot} = \delta_t + \delta_f$$

The angle α can be obtained in terms of δ_f and l as follows (Fig. 5).

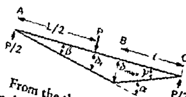


FIGURE 5 *A fractured tibia represented as a beam AC on two end supports distance L apart, with a concentrated load P. B indicates the fracture at distance l from nearer end support. δ_f is the displacement at the mid-point of AC, α is the angle of deflection at the callus, and δ_{max} the maximum displacement. P/2 is the reaction at the end supports*

From the theorem relating to the external angle, $\alpha = \beta + \gamma$. Since for small angles the tangent is nearly equal to the angle itself, $\beta = \delta_f/(L/2)$ and $\gamma = \delta_{max}/l$. But, from the theorem on similar triangles, $\delta_f/(L/2) = \delta_{max}/(L-l)$; thus $\delta_{max} = 2\delta_f(L-l)/L$. Hence, $\gamma = 2\delta_f(L-l)/Ll$. Inserting these values of β and γ in the equation $\alpha = \beta + \gamma$, we have

$$\alpha = 2\delta_f/L + 2\delta_f(L-l)/Ll$$
$$= 2\delta_f/l$$

But the bending moment acting on the spring joint $M = Pl/2$. Therefore,

$$C = Pl^2/4\delta_f \quad \ldots \quad [10]$$

where C is the stiffness of the callus in the model for the fractured bone. In the course of healing C increases inversely as the deflection of the callus δ_f. The equation is valid when the load-deflection curves of the fractured bones are linear, as they were in most cases at the stage of clinical stability.

It is of interest to see how the stiffness develops in the callus independent of the dimensions of the callus. In the model the spring joint is substituted by a beam of very short length s. $C = M/\alpha$, but for a beam $\alpha = Ms/E_f I_f$, and hence $C = E_f I_f/s$. But since $C = Pl^2/4\delta_f$ and thus we have:

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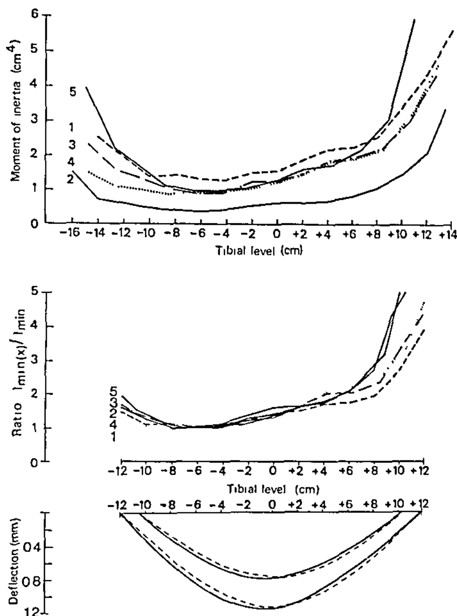


FIGURE 4 *Top.—Variation of the minimum moment of inertia of the sections along the tibia. Specimens 1—5.*

Middle.—Variation of the ratio $I_{min(x)}/I_{min}$ along the tibia for the same specimens

Bottom.—Deflection of specimen 2 (continuous line) and of an ideal beam loaded by a force of 5 kgf, with the end supports 24 and 21 cm apart (broken line)

of the shear accompanying bending. As such a model could not be applied in practice and would be understood only by specialists in the mechanics of materials, a simple model was chosen where the callus is first regarded

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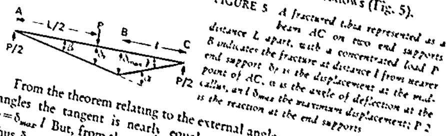


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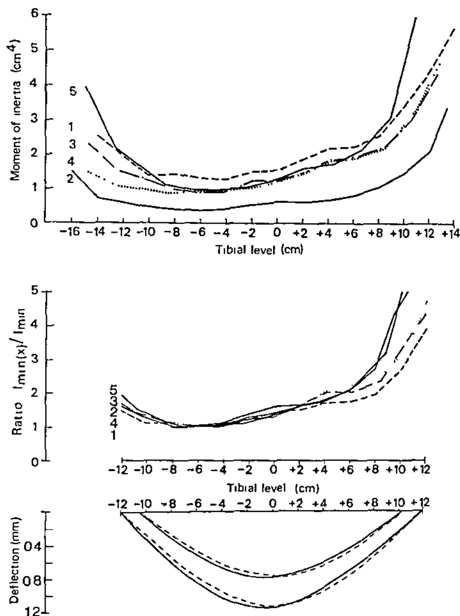


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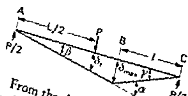


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If the three beams are taken to represent the fractured tibia, E_f, in eqn. [11], is the modulus of elasticity, I_f the moment of inertia and δ_f the deflection of the callus, which has a very short length of s.

δ_f is calculated in the following way. The bone fragments corresponding to the two beams have an observed deflection that is regarded as being equal to the observed deflection of the sound tibia, v_t. By subtracting v_t from the observed deflection of the fractured tibia, v_{tot}, the deflection of the callus is obtained. Thus,

$$\delta_f = v_{tot} - v_t \quad [12]$$

The ratio s/E_f is a measure of the stability of the callus. Neither s nor I_f can be determined. Since the former moment of inertia of the bone should be recovered on healing, the moment of inertia of the callus, I_f, was considered to be equal to that of the sound tibia at the level corresponding to that of the fracture. It is obtained as a multiple of I_{min} from the curves for the ratio $I_{min(x)}/I_{min}$ (Fig. 4, *middle*).

When a fracture heals the deflection of the callus decreases and δ_f approaches zero; thus E_f approaches very high values.

STATISTICAL METHODS

In the evaluation of the results the usual statistical methods were applied and the procedures are to be found in *Statistical Methods* by G. W. Snedecor and W. G. Cochran (1967).

The results of the measurements on the right and left tibias or of different methods of measurements were compared by analysis of variance, and the probabilities, P, of hypotheses set up were determined by means of the F ratio. Student's t was used to determine confidence intervals for the observed means.

Linear regression analyses were performed by the method of least squares.

IV. Methods

MEASURING INSTRUMENT

The instrument consists of an aluminium beam (*4* in Fig. 6), referred to as the "measuring beam", three stainless steel pins (*1*, *2* and *3* in Fig. 6), a template *5* and a measuring cylinder *6* containing a force and a position transducer, which are connected *via* an electronic system. In each end of the beam are four holes, located 7.5, 9, 10.5 and 12 cm from its midpoint. A pin inserted in one of the holes can be locked in position. The central part of the beam is in the form of a cylinder; into this fits the measuring cylinder which can be moved in relation to the beam and fixed in selected position with the lever *9*. The cylinder holder also takes the template *5*, by means of which the central pin is inserted in its correct position.

Pins *1* and *3*, the outer pins, have a shaft 4 mm in diameter which ends in a needle 18 mm long and 1.5 mm in diameter. This is ground to a point on four sides to give a semi-angle of 10°; the extreme end of the needle has the form of a cone, to prevent it turning over on insertion into the bone (Fig. 7). The middle pin is essentially the same as the outer pins, except that its shaft is furnished with a guide and a thread so that it can be locked to the shaft of the template or the shaft of the measuring cylinder.

The cylinder constitutes a housing for a position transducer *10* and a force transducer *12* The shaft *11* runs through the position transducer and is connected to the force transducer, to which is also connected a screw with a wheel *13*

The position transducer (Bofors Type RLL-1) is designed for static and dynamic determinations of positions within ±12 mm, with a deviation in linearity of ±0 5 per cent. The sensory component consists of a differential transformer with a movable core connected in the shaft *11*. The calibration values given by the manufacturer are accurate to 0.5 per cent for the temperature range 10—30°C.

The force transducer (Bofors, Type KRK-2) has a measuring area of range 0 to ±10 kgf. The sensory component consists of a metal cylinder, whose axis is perpendicular to the direction of the applied force, and

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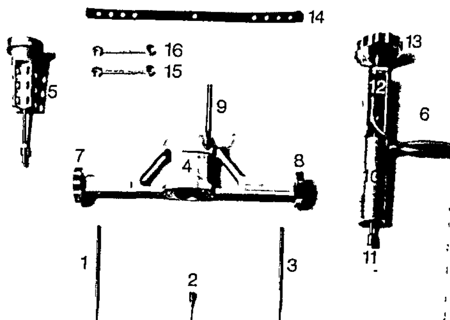


FIGURE 6 *The measuring instrument.*

1, 3 *Outer pins*
2 *Middle pin*
4 *Measuring beam*
5 *Template for positioning of middle pin*
6 *Measuring cylinder with built-in position transducer*
7, 8 *Wheels for locking outer pins*
9 *Lever for locking measuring cylinder*
10 *Position transducer, built-in*
11, 13 *Wheel 13 for displacering shaft 11 on force transducer, the shaft passes through the position transducer to apply force to the bone*
12 *Force transducer*
14 *Template for ensuring correct position of local anaesthetic*
15, 16 *Spanners for nut on shaft 11*

inside which are four strain gauges, attached at different distances from each other. When loaded, the cylinder is deformed so that its cross section is elliptical and the change in the radius of curvature of the cylinder is registered by the strain gauges, which form a 4-armed measuring bridge. The force transducer is connected to a transducer amplifier indicator, (Bofors, Type BKI-1), which contains circuits for measurement, and for balancing and calibration of the transducer bridge, and an amplifier. The deviation from linearity and hysteresis are less than 0.2 per cent and the calibration accuracy ±0.5 per cent.

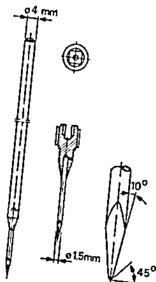


FIGURE 7 *Left—Outer pin. Centre—Middle pin Right—Enlargement of the pin tip showing conical shape of end.*

The signals produced by the position and force transducers are led to an X-Y recorder (Moseley, Model 7035 A), which registers a load-deflection diagram, accuracy ±0.2 per cent; linearity ±0.1 per cent. The *Y* coordinate denotes the displacement of the middle pin in relation to the position transducer, and the *X* coordinate the compressive or tensile force acting on the pin. The instrument can be set so that a full-scale reading on the Y-axis corresponds to a displacement of 0.5, 1, 2, 5 or 10 mm, and the full-scale deflection on the *X*-axis to a force of 1, 5 or 10 kgf. For most of the measurements in the investigation the full-scale deflection represented 0.5 mm and 5 kgf, respectively.

PRINCIPLES OF MEASUREMENT

The tibia is loaded by fixing the measuring beam to the bone with the outer pins and applying a bending force between the beam and the bone by means of the screw which moves the middle pin towards or away from the bone.

The method of measurement is based on the principle governing the bending of two beams connected at the ends and subjected to a bending force applied at the midpoint. In the present case one of the beams consists of the tibia and the other of the measuring beam. By regarding the tibia as a beam in the composite mode of loading it is possible to apply the

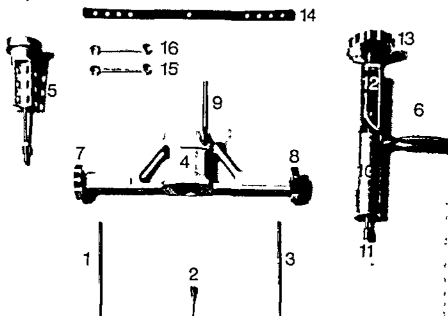


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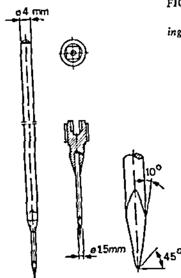


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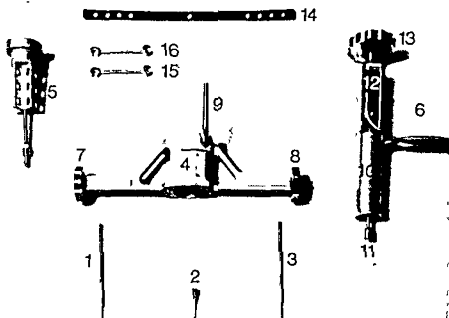


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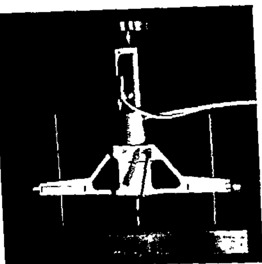


FIGURE 9 *The measuring instrument bolted to a steel beam used for checking that the deflection at a bending force of 5 kgf lies within the pre-determined limits*

beam was bolted (Fig. 9). The same bar was used for measuring the deformation of the measuring beam, as described below.

MEASURING ERROR

The position transducer indicates the total deflection of the beam and the object when a load is applied. The deflection of the beam was determined by fixing it to a steel bar measuring 32 by 32 by 300 mm made of 1.5 mm sheet steel. It was fixed with pins, the tips of which were soldered to bolts. The outer bolts were connected to the bar at an interval of 24 and 21 cm.

The deflection of the steel bar produced by a bending force of 5 kgf exerted by the middle pin is theoretically 3.8 µm for 24 cm and 2.5 µm for 21 cm. The deflection of the steel bar and the measuring beam with 24 cm between the bolts was 24.2 µm (range 22—27; $n=11$) for 5 kgf, and 48.5 µm (range 44—52; $n=8$) for 10 kgf. With 21 cm between the bolts the deflection was 14.9 µm (range 13—17; $n=11$) for 5 kgf, and 29.7 µm (range 27—32; $n=11$) for a force of 10 kgf.

The total mutual displacement of the tibia and the beam recorded by the position transducer includes the local movement of the cortex around the needles. As a compressive force on the outer pins will result in a tensile force on the middle pin, and *vice versa*, the error due to this local deformation of the bone consists of the displacement of the middle pin and half the sum of the displacement of the outer pins.

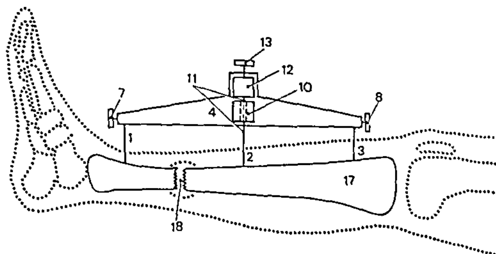


FIGURE 8 *The instrument mounted on a fractured tibia. See legend to figure 6. 17 Tibia 18 Fracture.*

principle pertaining to the deflection of a straight uniform beam simply supported and loaded at its midpoint.

The load is applied by turning the wheel *13* (Fig. 8) so that the shaft *11* with the middle pin *2* presses against the bone *17*. The tibia and the measuring beam are thus bent with their convexities in opposite directions with a compressive force *P*; the reaction *P/2* produces a tensile stress in each outer pin. When the measuring beam and the bone are deflected in this way the outer pins, which are locked in the beam and fixed in the bone, will bend with their convexities towards the middle pin; when the shaft *11* is subjected to a tensile force, the opposite loading conditions will obtain, so that the tibia and the measuring beam are bent towards each other. The deflection is thus measured in both positive and negative directions.

CALIBRATION

The X-Y recorder was connected to the position and force transducers and the instruments were calibrated and the linearity was checked over various measuring ranges. On several occasions during the course of the investigation the force transducer was calibrated against a load of 5 kgf and the reading on the X-Y recorder was checked. The position transducer was checked with the aid of pieces of sheet metal, whose dimensions had been determined with a micrometer screw gauge. No corrections were required during the course of this investigation. The instrument was also calibrated in a simpler way—against a steel bar to which the measuring

articular space of the knee or the medial malleolus. A local anaesthetic is administered at the intended sites in the skin and down towards the periosteum. The correct location of the anaesthetic is ensured by using the template *14* (Fig. 6), which consists of a stainless steel strip with holes corresponding to the positions of the middle pin and the pin distances on the measuring beam.

The outer pins are inserted in the holes in the beam and locked by gentle tightening of the wheels *7* and *8*. On the shaft of the template *5* the middle pin is fixed and the template inserted in its cylindrical holder. The pins are placed perpendicular to the medial surface on the tibia. With a light tap of a hammer the pins are inserted through the skin and periosteum down to the bone surface. The wheels *7* and *8* are then loosened and while the beam is held in one hand the pins are hammered about 2 mm into the cortex. They must be securely held by the bone but not penetrate to the marrow space. The outer pins are inserted first, followed by the middle one. The outer pins are locked to the measuring beam by tightening the wheels *7* and *8*. The nut on the shaft passing through the template is unscrewed from the middle pin, and the template with the shaft removed. After the position and force transducers have been set at zero, the measuring cylinder is locked to the middle pin by the nut on the shaft with the aid of spanners *15* and *16*. When the measuring cylinder is in place it is locked to the beam by tightening the lever *9*. As the measuring cylinder cannot be sterilized, from now onwards the sterility in the investigation is broken and the greatest care must be observed to avoid infection of the small lesions due to the

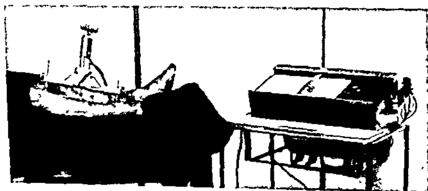


FIGURE 10 *The measuring instrument applied to the bone in the living patient for measurement of deflection On the right is the X—Y recorder, and below it the transducer, amplifier, and bridge*

The deformation of the actual pins also constitutes a source of error, but in measurements on bone this does not amount to as much as 1 per cent of the total deformation.

The sum of the deformation of the measuring beam, of the cortex around the pins and of the pins themselves was determined as follows. Twelve tibia specimens were sawn through their length, ground plane on the surface that was to be placed against the steel bar, and fixed to this bar with six bolts. Each specimen was tested twice at the two pin distances 24 and 21 cm. ("Pin distance" refers to the distance between the outer pins.) The deflection in the negative and positive directions produced by a load of 5 kgf was determined five times in each direction. There was no difference in the deflections in the two directions; the mean for the pin distance of 24 cm was 42.9 μm (range 32—63) and for 21 cm it was 31.3 μm (range 22—41). These values *minus* the deflection of the steel bar for the respective pin distances gives the correction to be subtracted from the observed measured displacement in an examination of the deflection of the bone. For a force of 5 kgf the corrections were 39 μm and 29 μm with 24 and 21 cm between the outer pins.

MEASURING TECHNIQUE

The instrument is intended for use in diaphyseal fractures of the long bones. The tibia was chosen for the investigation because fractures of this bone are common and not infrequently display delayed union.

The level at which the instrument shall be placed on the tibia is decided by the position of the fracture. The deflection is greater the closer the middle pin is to the fracture; this distance should not be less than 2 cm, because during the union the cortex becomes softer and does not provide so firm a hold for the pin. The mean distance from the centre of the fracture to the pin was 60 mm. For extreme distal or proximal sites of fracture an outer pin may have to be placed in the malleolar and condylar part of the tibia; here the cortex is thin and there is a risk that the pin will not be held firmly enough. There is also a risk that when it is being inserted the cortex may easily be penetrated, with consequent weakening of the hold.

In such cases, it would be wiser to use a distance of 21 cm or less, but for the sake of uniformity in the assessment of the results 24 cm was used in all but two cases, and here the distance was 21 cm.

When the level at which the instrument is to be placed has been determined it is marked on the fractured leg, and also on the sound leg. The level of the middle pin was measured as the distance from the medial

articular space of the knee or the medial malleolus. A local anaesthetic is administered at the intended sites in the skin and down towards the periosteum. The correct location of the anaesthetic is ensured by using the template *14* (Fig. 6), which consists of a stainless steel strip with holes corresponding to the positions of the middle pin and the pin distances on the measuring beam.

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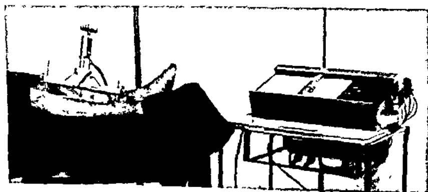


FIGURE 10 *The measuring instrument applied to the bone in the living patient for measurement of deflection On the right is the X—Y recorder, and below is the transducer, amplifier, and bridge*

pins. The legs rest on a foam rubber cushion, usually slightly everted so that the instrument is perpendicular and rests on the bone, or else it is steadied with one hand (Fig. 10).

The instrument is now ready for measurement of the load on, and deflection of, the tibia. When the wheel of the cylinder is turned clockwise the middle pin moves down to bear on to the bone and the X-Y recorder registers a curve in the negative direction of x. The wheel is turned until a full reading corresponding to a compressive force of 1, 5 or 10 kgf is obtained on the middle pin, which produces a deflection in the negative direction. By turning the wheel counterclockwise the compressive force on the middle pin is first decreased to zero and then a tensile force is produced until a full-scale deflection is obtained in the positive direction of x. Examples of the curves recorded for the tibia specimens are shown in figure 11.

It is important to ensure that the pins do not loosen during the measurements. To avoid disturbing the outer pins while the middle pin is being hammered in they should not be locked until afterwards. If a pin penetrates the cortex it may slide in relation to the bone. Curve C in figure 12 shows how a change on the position of the middle pin by turning the wheel on the measuring cylinder results in an increase in the reading from the position

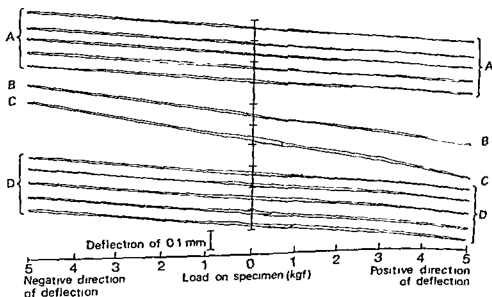


FIGURE 11 *Load-deflection curve for tibia specimen*
A, B.—Pin distance of 21 cm, load 5 and 10 kgf, respectively
C, D.—Pin distance of 24 cm, load 10 and 5 kgf, respectively

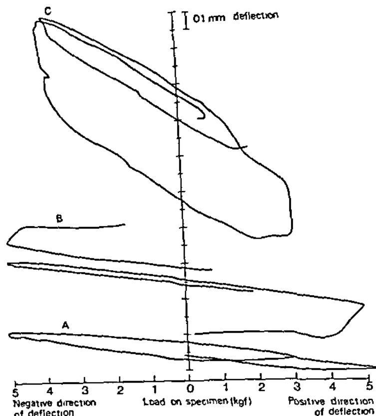


FIGURE 12 *Load-deflection curve for vital tibia.*
A—*Curve showing hysteresis due to high friction of measuring cylinder shaft against position transducer owing to oblique middle pin*
B—*Because the pin had loosened the curves tend towards the axis of y after an initial short increase in deflection.*
C—*Slipping of the pin produced a large displacement parallel to the axis of y, with no change in applied force*

transducer—that is along the y-axis of the recorder—but no increase in the force already applied, which remains constant at a value of x corresponding to the force required to overcome the frictional resistance of the pin in the bone.

When a pin loosens, the stress in the beam is relieved and the beam recovers its original shape, the resulting displacement producing an increase in deflection. The force on the middle pin is also relieved and x again be-

pins. The legs rest on a foam rubber cushion, usually slightly everted so that the instrument is perpendicular and rests on the bone, or else it is steadied with one hand (Fig. 10).

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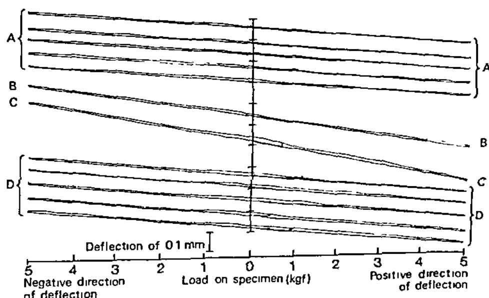


FIGURE 11 *Load–deflection curve for tibia specimen*
A, B.—Pin distance of 21 cm, load 5 and 10 kgf, respectively
C, D.—Pin distance of 24 cm; load 10 and 5 kgf, respectively

The magnitude of the deflection within the fracture is strongly dependent on its distance from the nearer outer pin. On films of the fractured tibia the distance from the middle pin to the line of fracture is measured in the projection that gives a side view of the pins. Two distances are determined, namely, that from the middle pin to the fracture line on the same side as the pin is inserted, and that to the fracture line in the cortex of the opposite side. The distance from the centre of the fracture to the level of the middle pin is calculated as half the sum of the above two distances multiplied by the enlargement factor. The distance so obtained subtracted from the distance between the middle pin and the relevant outer pin gives the distance from the nearer outer pin to the fracture—l in eqn. [11].

The moment of inertia for the narrowest part of the sound tibia shaft is calculated. On films taken with the projection giving a lateral view of the pins the narrowest part of the tibia is found, and as far distally as possible within this part measurements are made of the distance d, the thickness of the tibia to the medial surface. The diameter a of the marrow space at the same level is also determined. The distance of the middle pin from this level in this projection is marked off from the middle pin on the radiograph exposed with the perpendicular projection, and here the width b of the tibia is determined.

The dimensions so obtained are corrected with respect to the enlargement factor and entered in eqn. [8]. $I_{appr}=0.042\ bd^3—0.049\ a^4$, which gives an approximate value of the moment of inertia of the tibia at it narrowest part.

comes zero. Curves B in figure 12 recorded when a pin loosened show how the force diminishes and the curves run parallel with the x-axis towards zero.

When the middle pin is being inserted it may bend or be guided along an oblique path in the bone substance. This is indicated by difficulty in getting the measuring cylinder into position on the middle pin, it being necessary to move its head slightly to the side before the shaft of the measuring cylinder can be screwed fast. This, however, will result in too large a deflection, since the position transducer also registers any deformation of the pin. The error will be greatest if the deviation of the middle pin from the plane of deflection of the instrument occurs in the transverse plane of the tibia, because then a torque will be produced that will also tend to bend the outer pins in a transverse plane. While a middle pin is inclined in the bending plane of the tibia it will not tend to rotate the bone. This situation is reflected in a curve as an increase in hysteresis. It is due to the fact that the axis of the measuring cylinder bears against the housing of the position transducer, and the force required to overcome the resulting friction is recorded without simultaneous change in the position of the axis; this is illustrated by curve A in figure 12.

When the measurement is completed the nut holding the middle pin is loosened and the lever *9* and the measuring cylinder are removed. The outer pins are unlocked and the beam lifted off.

The measuring procedure is then repeated on the sound leg and radiographs are taken with all the pins in place in both tibias.

RADIOGRAPHIC EXAMINATION

After the measurements radiographs are taken with the exposure data kept constant for each patient. On the radiographs an estimate of the distance between the pins and the fracture is obtained and the dimensions of the tibia are measured for the determination of the moment of inertia; they also serve for the usual examination of the fracture. The radiographs are taken in two projections, one perpendicular to the pins and in the plane of the medial surface of the tibia, and the other parallel to the pins. The central ray is centred on the middle pin. As the distance between the outer pins is known a reliable enlargement factor can be obtained by measuring the distance on the radiograph. By means of this factor the dimensions of the tibia and the distance of the pins from the fracture can be accurately determined.

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DETERMINATION OF DEFLECTION

The length of the tibia was taken as the distance between the distal articular surface of the bone and the middle portion of the articular surface of the medial condyle. To obtain the midpoint of the tibia, one half this distance was then marked off from these articular surfaces on the medial surface. The lengths of the specimens are given in table 2. The middle pin of the instrument was anchored at a point half way along and across the tibia, perpendicular to the medial surface (Fig. 13). One measurement was

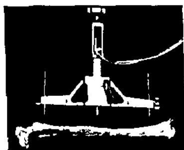


FIGURE 13 *Measuring instrument applied to a bone specimen*

made with each of the pin intervals 24 and 21 cm. The middle pin was subjected to alternately tensile and compressive forces of up to 5 kgf—both away from and towards the measuring beam (positive and negative directions). No difference in the deflection for these two directions was recorded. Each measurement was repeated five times in both directions and the mean deflection for the 10 measurements for a load of 5 kgf was determined. The recorded curves for a tibia are presented in figure 11.

It was impossible to determine the error of deflection for a single specimen by replicate measurements because for the second measurement the experimental conditions are different. For example, any alteration in the fixation of the pins would result in a change in the plane of bending and the moment of inertia. The error of deflection for a single observation was therefore determined in two ways, namely by measuring the deflection at pin distances of 24 and 21 cm and by comparing the deflections on pairs of

V. Measurements on autopsy tibias

One of the objects of the experiments on autopsy specimens was to determine the error contained by the recorded value of the deflection of the tibia in a single observation. Another was to check the agreement between the values of the moment of inertia determined by (*i*) numerical integration, (*ii*) with an integrator and (*iii*) by application of eqn. [8] for $I_{appr.}$

MATERIAL

The pairs of tibia specimens were obtained at autopsies performed at the National Forensic Station from persons that had died through trauma or suicide and that, so far as was known, had not had any disease that may have affected the bones. The mean age of these subjects was 32 years (range 22—44). Other data are presented in table 1.

The fresh bone specimens were preserved in Ringer's solution. The deflection measurements were usually performed on the day the specimens were prepared, and never later than the following day. Pending some later examination they were stored at —20°C in polythene bags containing Ringer's solution. Throughout the work on the specimens the moisture con-

TABLE 1 *Autopsy series.*

	Age	Sex	Cause of death		Age	Sex	Cause of death
Subject 1	26	M	Suicide	*Subject* 12	31	F	Suicide
2	32	F	"	13	22	M	Subarachnoid haemorrhage
3	26	F	"	14	44	M	Suicide
4	39	M	Cranial fracture	15	34	M	"
5	37	M	Suicide	16	35	M	Epileptic convulsions
6	24	M	"	17	39	M	Suicide
7	30	M	"	18	26	F	Thoracic and abdominal traumata
8	26	M	"	19	31	M	Suicide
9	39	M	"	20	29	M	"
10	30	M	"				
11	39	F	Abdominal trauma				

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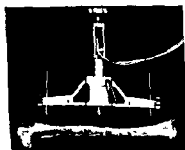


FIGURE 13 *Measuring instrument applied to a bone specimen*

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MATERIAL

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	4	39	M	Cranial fracture		15	34	M	,,
	5	37	M	Suicide		16	35	M	Epileptic convulsions
	6	24	M	,,		17	39	M	Suicide
	7	30	M	,,		18	26	F	Thoracic and abdominal traumata
	8	26	M	,,		19	31	M	Suicide
	9	39	M	,,		20	29	M	,,
	10	30	M	,,					
	11	39	F	Abdominal trauma					

tibias. In the former method it should be possible to keep the same plane of bending.

No measurements were made for the 21-cm distance for either tibia of subject no. 1, nor for the right tibia of subject no. 4. The marked hysteresis displayed by the curves for subject no. 9, left tibia, 24-cm pin distance, is due to an oblique position of the middle pin, and the value for this curve was therefore discarded.

The values of δ_{24} and δ_{21} obtained after correction for the error of the method (instrument deformation, page 24) are given in table 2.

DETERMINATION OF THE MOMENT OF INERTIA

The magnitude of the deflection is dependent on the moment of inertia I and the modulus of elasticity E of the bone, and to enable a comparison of the deflection of different bones to be made the moment of inertia of the cross section was determined. This was done in three ways: (*i*) numerical integration, (*ii*) with an integrator and (*iii*) by using eqn. [8]. The transverse section of the tibia was chosen at the level where the thickness of the bone d was smallest and the moment of inertia of the section therefore lowest (page 13).

To obtain as accurate a comparison as possible of the deflection of different tibias the first two methods were used for replicate determinations of the moment of inertia.

(*i*) *Numerical integration*

The moment of inertia was determined numerically ($I_{min, n}$) from ink impressions of the cross section of tibia obtained on graph paper. The cross section had previously been ground plane on water-resistent sandpaper under water and the fat in the marrow space and the looser spongy bone scraped away. The section was placed so that the side included in the medial surface was parallel to one of the set lines of the graph paper. For each section the moment of inertia about the central axis was calculated twice, this was done by summing the products of the square of the distance of each millimetre square in the section area from the central axis, and adding to this total the sum of the moment of inertia of each millimetre square about its own central axis. The mean of the two values of the moment ($I_{min, n}$) is given in table 2.

(*ii*) *Integrator*

The cross section of the tibia was photographed with a millimetre scale placed in the same plane. The films were copied and enlarged by a factor

TABLE 2 *Results of measurements on the autopsy specimens. Length of tibia; moments of inertia obtained from equation [8] $I_{min\,appr}$, with integrator $I_{min\,i}$ and by a numerical integration $I_{min\,n}$; and the corrected deflection of the tibia for a load of 5 kgf at pin distances of 24 and 21 cm.*

Specimen		Length of tibia	Moment of inertia (cm⁴)					Deflection (μm)	
			$I_{min\,appr}$	$I_{min\,i}$	$I_{min\,i\,corr}$	$I_{min\,n}$	$(I_{min\,i\,corr}+I_{min\,n})/2$	24	21
Right	1	400	1.3267	1.3139	1.2186	1.3044	1.2615	34	—
	2	358	0.5165	0.4940	0.4685	0.4865	0.4775	94	68
	3	356	0.8966	0.8212	0.7713	0.7695	0.7704	70	43
	4	397	0.8017	0.8653	0.8153	0.8529	0.8341	60	—
	5	340	1.0967	1.0340	0.9628	1.0090	0.9859	52	39
	6	378	1.4947	1.3512	1.4192	1.3984	1.4088	56	41
	7	420	0.8448	0.9037	0.8349	0.8512	0.8431	74	48
	8	360	0.5730	0.5476	0.5747	0.5932	0.5840	91	56
	9	376	1.0729	1.0270	0.9570	0.9249	0.9410	59	44
	10	382	1.1405	1.1360	1.0761	1.0738	1.0750	53	37
	11	337	0.4146	0.4297	0.4537	0.4302	0.4420	125	85
	12	327	0.7640	0.7002	0.6554	0.6335	0.6445	79	56
	13	393	1.0874	1.1910	1.1187	1.1176	1.1182	49	36
	14	360	0.9100	0.7701	0.7256	0.7250	0.7253	70	46
	15	350	0.6420	0.6321	0.5937	0.5739	0.5838	84	66
	16	384	1.5001	1.3203	1.2440	1.2715	1.2578	57	33
	17	388	1.2000	1.1325	1.0670	1.0920	1.0795	61	35
	18	304	0.4866	0.5568	0.5831	0.5910	0.5871	107	66
	19	376	0.8534	0.7567	0.8104	0.8405	0.8255	73	62
	20	355	0.9981	1.0494	1.1193	1.1080	1.1137	61	53
Left	1	398	1.3344	1.2498	1.3278	1.3665	1.3472	31	—
	2	358	0.4260	0.4121	0.4295	0.4414	0.4355	115	78
	3	356	0.9780	0.9076	0.9496	0.9317	0.9407	59	37
	4	396	0.7935	0.8268	0.8651	0.8570	0.8611	61	43
	5	340	0.9276	0.8836	0.9281	0.8445	0.8863	63	52
	6	376	1.4039	1.3575	1.4258	1.3908	1.4083	50	41
	7	419	0.7460	0.8185	0.8590	0.8221	0.8406	67	46
	8	362	0.5250	0.5227	0.5486	0.5434	0.5460	79	57
	9	380	1.1370	0.9261	0.9660	1.0476	1.0068	88	43
	10	379	1.0340	1.0568	1.1160	1.1363	1.1262	56	41
	11	338	0.6044	0.6081	0.6330	0.6088	0.6209	91	65
	12	330	0.6537	0.6156	0.6421	0.6034	0.6228	88	64
	13	393	1.1122	1.2026	1.1321	1.3197	1.2259	57	31
	14	360	1.0665	0.9060	0.9490	0.8465	0.8978	64	46
	15	350	0.5909	0.5678	0.5350	0.6141	0.5746	98	63
	16	379	1.5843	1.4733	1.3882	1.4011	1.3947	51	30
	17	387	1.0812	1.0505	0.9898	1.1108	1.0503	56	46
	18	314	0.4666	0.5012	0.5218	0.5320	0.5269	134	78
	19	371	0.8568	0.7564	0.7914	0.7914	0.7914	74	45
	20	355	1.0473	1.0491	1.0943	1.0905	1.0924	73	49

TABLE 3 *Analysis of variance for the corrected deflections of tibia specimens. The values of δ_{24} and 1.49 δ_{21} are analysed The values of δ_{24} and δ_{21} are given in table 2*

Source of variation	Degrees of freedom	Mean square	F ratio	P
Specimen	35	866		
Pin distance	1	65	$F_{1,35}=1.81$	>0.05
Error and interaction[a]	35	36		

[a]Relative error for a single measurement: $100(36)^{1/2}/75=\pm 8$ per cent

There was no significant difference between δ_{24} and 1.49 δ_{21}. The relative experimental error for a single determination of the deflection was thus ± 8 per cent.

The experimental error incurred in measuring the deflection was also determined in another way. The modulus of elasticity was then assumed to be the same for the two tibias of a subject. The relative error of the modulus of elasticity is equal to the square root of the sum of the squares of the relative errors of the moment of inertia and the deflection, as the modulus of elasticity is related to the product of the deflection and the moment of inertia, according to eqn. [2]. Thus, the error in the corrected observed deflection of the tibia can be calculated if the relative errors of the determinations of the modulus of elasticity and the moment of inertia are known. The apparent modulus of elasticity "E_{24}" and "E_{21}" was calculated from the mean value of $I_{min\ i\ corr}$ and $I_{min\ n}$ for each specimen, and the corresponding values of the deflections δ_{24} and δ_{21}. In the analysis of variance for the determination of the experimental error, the same model as in the previous experiment was used. The two factors were the subject and the side. The interaction between subject and side could not be isolated from the error of measurement. The analyses of variance presented in table 4 show no significant difference between the right and left sides for either "E_{24}" or "E_{21}". The means for "E_{24}" and "E_{21}" were 2.6×10^3 and 2.4×10^3 kgf/mm², respectively. The corresponding experimental relative errors were ± 8 and ± 9 per cent.

The experimental relative error in determining the moment of inertia was ± 4 per cent, as reported below. For the mean of two determinations of $I_{min\ i\ corr}$ and $I_{min\ n}$, as used in the calculation of the apparent modulus of elasticity, the corresponding relative error will be ± 3 per cent. Thus, the relative error for a single measurement in δ_{24} was obtained as ± 7 per cent and in δ_{21} as ± 8 per cent.

of 10 and the moment of inertia was ($I_{min\ n}$) determined with an Amsler integrator Type 2002. The method error for the integrator is ± 1 per cent for the measurement of area and ± 2 per cent for moment of inertia. The sections were placed so that the side included in the medial surface was parallel with the integrator ruler. Two determinations of $I_{min\ i}$ were made on each section; their mean and the corrected values of $I_{min\ i}$, designated ($I_{min\ i\ corr}$), are given in table 2. The correction takes account of non-uniform enlargement.

(iii) Formula

On the photographic enlargements of the sections produced for method (*ii*) measurements were made of the depth of the tibia (*d*), the width of the section (*b*) and the diameter of the marrow space (*a*), as these dimensions would be obtained by radiographic projection by the technique mentioned on page 29. These values were inserted in eqn. [8] for the approximate moment of inertia: $I_{min\ appr} = 0.042\ bd^3 - 0.049\ a^4$.

RESULTS

Deflection

As is evident from eqn [9], if the tibia is regarded as a simply supported beam loaded at its midpoint, the corrected deflections, δ_{24} and δ_{21}, are related as the cubes of the respective outer pin distances multiplied by the constants 1/67 and 1/66, respectively. The theoretical ratio of δ_{24} and δ_{21} is then determined thus: $(24.1^3/67)/(21.0^3/66)$, or 1.49. By dividing the value of δ_{24} by that of δ_{21} from each specimen, an experimental value for the ratio was obtained. A preliminary analysis disclosed no difference between the quotients for the right and the left tibias. The mean for all 36 specimens was then 1.46. The theoretical ratio lay within the 99 per cent confidence interval for the experimental ratio.

By multiplying δ_{21} by the theoretical ratio 1.49, a value is obtained that can be compared with δ_{24}. The series of values δ_{24} and 1.49 δ_{21} were submitted to analysis of variance to determine the experimental error incurred in the deflection of the tibia (Table 3). As it was only the values for one and the same bone that were compared, determinations on both right and left tibias could be used in the determination of the measurement error. In the analysis of variance the two series of deflection values from the tibias were treated as a two-factor experiment, the two factors being the specimen and the pin distance (*Snedecor & Cochran*, Chapter 12). However, the sum of the squares of interaction cannot be separated from the sum of the squares of the error (Table 3).

TABLE 5 *Analysis of variance for the minimum moment of inertia of the narrowest tibia section derived from values of $I_{min\ appr}$ and $I_{min\ i}$ (Table 2)*

	Degrees of freedom	Mean square	*F* ratio	*P*
Source of variation				
Side, I	1	0 00437	$F_{1,19}$ = 0.55	>0 05
Method, II	1	0 02000	$F_{1,19}$ = 4 00	>0 05
Subject, III	19	0 35981		
Interaction, I & II	1	0 00001		
" I & III	19	0 00801	$F_{19,19}$=10.97	<0 001
" I & III	19	0 00500	$F_{19,19}$= 6 85	<0 001
Error and interaction* I, II & III	19	0 00073		

*Relative error for a single determination $100(0\ 00073)^{1/2}/0\ 91 = \pm 3$ per cent

Means $I_{min\ appr}$=0 92; $I_{min\ i}$=0 89 cm⁴

In exactly the same manner the values of the moments of inertia arrived at by numerical integration ($I_{min\ n}$) and the corrected values obtained by the integrator method ($I_{min\ i\ corr}$) were analysed. These two series of values are presented in table 2, and the results of the analysis of variance are given in table 6. There was no significant difference between sides or between methods. A highly significant lack of additivity between side and subject was obtained but in this experiment there was no significant lack of additivity between method and subject.

The approximation method for determining the moment of inertia contains an error the magnitude of which increases with the disparity between

TABLE 6 *Analysis of variance for the minimum moment of inertia of the narrowest tibia section derived from values of $I_{min\ i\ corr}$ and $I_{min\ n}$ (Table 2)*

	Degrees of freedom	Mean square	*F* ratio	*P*
Source of variation				
Side, I	1	0 02034	$F_{1,19}$=2 85	>0 05
Method, II	1	0 00185	$F_{1,19}$=1 45	>0 05
Subject, III	19	0.32696		
Interaction, I & II	1	0 00001		
" I & III	19	0 00713	$F_{19,19}$=5.17	<0 001
" I & III	19	0 00128	$F_{19,19}$=0 93	>0 05
Error and interaction* I, II & III	19	0 00138		

*Relative error for a single determination $100(0\ 00138)^{1/2}/0\ 89 = \pm 4$ per cent

Means $I_{min\ i\ corr}$ – 0 89, $I_{min\ n}$=0 90 cm⁴

TABLE 4 *Analysis of variance for the apparent modulus of elasticity of the tibia specimens Separate analyses were performed for the pin distances 24 and 21 cm*

	Degrees of freedom	Mean square $\times 10^6$	F ratio	P
	PIN DISTANCE 24 cm			
Source of variation				
Subject	18	3048		
Side	1	679	$F_{1;18}=1.61$	>0.05
Error and interaction[a]	18	423		
	PIN DISTANCE 21 cm			
Subject	17	2385		
Side	1	455	$F_{1;17}=0.88$	>0.05
Error and interaction[b]	17	519		

[a]Relative error for a single determination: $100(423\times10^6)^{1/2}/258{,}000=\pm8$ per cent

[b] " " " " " " : $100(519\times10^6)^{1/2}/241{,}000=\pm9$ per cent

Thus, the relative error of the deflection of the tibia for a single determination was ±8 per cent for both methods of determining the experimental error.

Moment of inertia

The values obtained for the moment of inertia from eqn [8] $I_{min\ appr}$ and from the determination with the integrator I_{min}, were compared (Table 2). As they were determined from the same enlarged photographs, no refined correction for the small difference in the enlargement factor between different pictures is necessary. By analysis of variance, the factors considered to influence the measurements were examined. The main sources of variation were side (I), method (I) and subject (III). There was also the interaction between side and method (I &II), side and subject (I & III), and method and subject (II & III) and the three-factor interaction (I, II & III) could not be separated from the experimental error. Statistical models are given in *Snedecor & Cochran*, Chapter 12.

The analysis of variance (Table 5) shows that there is no significant difference between sides or methods and there is a highly significant lack of additivity between side and subject and also between method and subject. The estimated relative error for a single determination of $I_{min\ appr}$ is ±3 per cent.

TABLE 7 *Angle β between chosen plane of bending for the instrument and the bending plane for the minimum moment of inertia Increase in the moment of inertia corresponding to observed angle β Ratio I_{max}/I_{min}*

Subject	1	2	3	5	13	14	18
Angle β between chosen and principal central axis; degrees	7.3	−0.5	1.5	9.3	7.8	−1.5	<0.1
$I\beta - I_{min}$ as a percentage of I_{min}	1.4	<0.1	<0.1	2.2	0.5	0.2	<0.1
I_{max}/I_{min}	1.85	1.29	1.54	1.96	1.28	2.56	1.79

The deflection curve of a particular tibia is unique. As pointed out on page 15, this curve is dependent on the variation of the minimum moment of inertia for the section along the length of tibia. If the weakest section were to be located at the level of the middle pin, this would be the site of the greatest possible deflection of the tibia.

As the centre of torsion and the centroid of the tibia section do not coincide, the deflection of the tibia will be combined with a rotation. The calculations show that in the least favourable case the error in the recorded deflection due to this rotation does not amount to more than +2 per cent.

Factors governing the moment of inertia

The moment of inertia is difficult to measure in spongy bone, but the narrowest part of the tibia contains only a small amount of such substance. It is difficult to draw a boundary between the cortical and the spongy bone, and the border has been chosen where the cavities of the spongy bone merge with the marrow space. Proximally and distally of the narrowest part of the tibia the spongy bone occupies an increasingly large proportion of the section, and it is difficult to judge its share of the moment of inertia. For other than the narrowest part, it is thus mainly the moment of inertia of the cortical bone that was determined. This means that the value for the sections with a greater proportion of spongy bone is on the low side.

Compact bone varies in porosity and there are divergent opinions on the effect of this structural factor on the physical properties of the bone (Evans, 1958; Smith & Walmsley, 1958; Currey, 1959; Vose, 1961; Sedlin & Hirsch, 1966; Blaimont, 1968; Evans & Bang, 1968). The fact that the subjects from which the bone specimens were obtained were not above 44 years of age would seem to rule out the possibility of osteoporosis and the specimens probably dit not differ essentially in porosity.

the configuration of the cross section and that of the standardized contour. This explains why the mean square of the interaction between method and subject is larger in the analysis of $I_{min\ appr}$ and $I_{min\ t}$ than in that of $I_{min\ t\ corr}$ and $I_{min\ n}$.

DISCUSSION

Factors affecting the deflection

The maximum deflection of the tibia is obtained if the bending force acts in the bending plane for the minimum moment of inertia of the section. Since the directions of the principal central axes are unknown at the time of the measurement, the recorded deflection will include the error due to the instrument being placed perpendicular to the medial surface of the tibia. If the direction of the load makes an angle β with the plane for maximum deflection of the tibia the bending will occur in a plane making an angle of φ with the plane for maximum deflection, where the relationship between these angles is given by eqn. [6]. The deviation of the recorded deflection from the maximum is obtained from eqn. [7]. By way of example, consider the case where $\beta = 15°$, $I_{max} = 1.5$ and $I_{min} = 1.0$; then $\varphi = 10.1°$. These values entered in the formula give $v_{obs} = 0.977\ v_{max}$. The recorded deflection of the tibia is thus 2.3 per cent smaller than the maximum deflection as a result of the angle between the plane perpendicular to the plane of the medial surface and the plane for maximum deflection of the tibia. As this angle will probably not exceed 15°, the given example will illustrate the influence of the angle between the planes on the error of the deflection in a most unfavourable case.

To see how the angle between the plane perpendicular to the medial surface and the bending plane for maximum deflection of tibia varies, the directions of the principal central axis of seven sections of widely different shapes were examined. The direction of one of the principal central axes lies in the plane for maximum deflection of the tibia. By means of the integrator the principal moment of inertia and the positions of the principal central axes were determined. The greatest value of the required angle was 9.3°, which implies an increase of 2.2 per cent in the corresponding moment of inertia from the minimum moment. The results from the other sections are given in table 7. The highest value for the ratio I_{max}/I_{min} was 2.6.

According to the determinations performed on autopsy specimens, the principal central axes in different sections are practically parallel (Fig. 3), and the tibia would thus not itself produce a rotation while being bent.

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The errors in the determination of the deflection and the moment of inertia will evidently affect the observed modulus of elasticity. A large error is due to the constant in eqn. [9]. An accurate determination of the modulus of elasticity would need a specific constant for each bone because of the individual structure of the tibia. It was to some extent surprising that there was not a greater difference in the constant for the five specimens for which it was calculated (standard deviation 5 per cent). With the mean of 1/67 for the constant obtained for the pin distance 24 cm, the mean for E_{24} was 1.85×10^3 kgf/mm^2; for the pin distance of 21 cm and the constant 1/66, the mean for E_{21} was 1.75×10^3 kgf/mm^2. The corresponding values for the relative experimental error were ± 8 and ± 9 per cent for a single measurement.

VI. *Clinical application*

MATERIAL

It was originally intended to record the development of stability in all cases of new fractures of the tibial shaft referred to this hospital, but it was soon found that some such fractures displayed good stability after as little as 6—8 weeks of immobilization and there were therefore no therapeutic grounds for performing measurements. Still less was it justified to shorten the first period of immobilization before the fracture had become stable merely to obtain values for the investigation. On the other hand, there were patients in whom healing was slow and did not occur in the usual time, where, to judge from the radiographs, the formation of callus was unsatisfactory of where there was delayed union or risk of pseudarthrosis. It is for such cases that the method was intended as an aid in the evaluation of the healing and the progress of the treatment. The first measurement of the stability of the fractured tibia was therefore not performed until a period had elapsed after the fracture; this ranged from 6 to 39 weeks, with an average of 19. Because of the risk of infection when the pins were inserted, no examination was made in the case of infected leg wounds. When the fracture was located in the extreme distal or proximal part of the tibia, so that the pins had to be inserted quite near the respective joints, no examination could be made because the malleolar and condylar areas afford an unreliable hold.

The material for the study comprised 40 patients with shaft fractures of the tibia, 3 of them with pseudarthroses. Measurements on the tibia of the sound leg of a patient with a trimalleolar fracture were included. Examinations were repeated on two or more occasions in 29 of the patients.

The mean age of the 26 men was 38 ± 16 years (range 17—66) and of the 14 women 48 ± 15 years (range 18—75). The difference between the means is not statistically significant, but the recorded difference points to the possible existence of different external factors responsible for the fracture in men and women.

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were performed with a pin distance of 21 cm the values were converted to corresponding ones for 24 cm.

The values recorded for the sound tibia are presented in table 8. Where there were two or more values, the variation due to the error of measurement could be separated from the biological variation by means of an analysis of variance. In this case there was an hierarchic classification with case and measurement as sources of variation (*Snedecor* & *Cochran*, Chapter 10).

Results

The male and female patients were assigned to separate groups. The mean observed deflection of the sound tibia was 97 μm for the men and 149 μm for the women. The corresponding relative errors for a single measurement were ±5 and ±9 per cent.

In the statistical analysis of the results 3 values for each of cases 18, 34, and 41 were omitted (indicated in parentheses in table 8) for the following reasons. For the first measurement on case 18 the middle pin entered obliquely to the side. The middle pin was carefully loosened, but on re-insertion it followed the same track as before. This was reflected in the recorded curve (Fig. 12, curve A), which, as expected, showed a larger deflection than the subsequent ones.

For case 34 the first deflection recorded differed from the subsequent ones owing to the position of the instrument; for a check of the radiographs showed that at the first registration the instrument was 2 cm proximal of its position for the later measurements. The distance of the middle pin from the narrowest part of the tibia for the first registration was 53 mm and for the four subsequent ones 31, 31, 34 and 30 mm. The large difference may be due to the long interval of 24 weeks between the first and second examinations.

Case 41 was an early one in the investigation, when no radiographs were taken with pin in place. In the first measurement the distal pin was located too far distally on the fractured tibia and the instrument was therefore intentionally placed at a more proximal level in the following examinations.

The values of the moment of inertia of the smallest section calculated from eqn. [8], $I_{min\ appr} = 0.042\ bd^3 - 0.049\ a^4$, are presented in table 9. The model for the statistical analysis is the same as for the analysis of the deflection. The mean moment of inertia for men was 0.94 cm^4 and for women 0.58 cm^4. The corresponding relative errors for a single measurement were ±4 and ±5 per cent.

One patient had a two-level fracture, the middle fragment being about 15 cm long. In 5 patients the shaft fracture was located proximally and in the other 34, distally. Seven were open fractures. In 4 cases osteosynthesis had been performed prior to the first measurement and 5 patients underwent a total of 7 operations after this measurement.

The first measurement of the deflection of the tibia was made on average 19 weeks (6—39) after the fracture or the most recent operation. Three patients with pseudarthroses were not included because the treatment had once been regarded as completed. The mean interval between the measurements was 8 weeks (range 3—24); the average was raised considerably by the long time often left between the last two measurements.

Because, at the beginning of this investigation the formula for the moment of inertia of the tibia (eqn. [8]) had not been calculated, the radiographic examination included no films taken with projections enabling the moment of inertia of the bone to be measured. For this reason the moment was not determined for all the stability examinations. So as not to increase the risk of infection, no pin that had loosened and passed out through the skin was re-inserted in the bone.

In some cases a pin loosened when the load was less than 5 kgf, and then the value was extrapolated to 5 kgf so as to enable a comparison to be made with those obtained in subsequent measurements. As the load-deflection curves were fairly linear, extrapolation would not appreciably increase the error of measurement. The extrapolated values are marked with an asterisk in the text and curves. All the curves from the measurements performed are presented.

MEASUREMENTS ON THE INTACT TIBIA

As the two tibias of any one person displayed close similarities and had practically the same flexural rigidity (*EI*), it is possible from the deflection and moment of inertia of the sound tibia to obtain an impression of the flexural rigidity of the other bone before the fracture. The relation between the observed deflections of the fractured and sound tibias affords a criterion of the stability of the fracture during the course of healing. By repeating the determinations of both deflection and moment of inertia the reproducibility of the clinical measurements could be ascertained. At the same time these values indicate the suitability of the method for determining the modulus of elasticity *intra vitam*.

The reported values relate to the deflection for a pin distance of 24 cm and a load of 5 kgf. In the case of two patients in whom measurements

TABLE 9 *Moment of inertia. (Cases with two or more values are used for analysis of variance)*

	Moment of inertia, cm⁴							
Male cases								
1 LH	817	.854	.869					
2 H W.	.759	.801	756					
3 S S.	1 186	1 251	1.307	1.238	1.210			
4 L B	.806	.886						
5 K.F	1 045							
6 L L.	886							
7 F S	.807							
8 N S	—							
9 G.W.	—							
10 G S.	1.158	1 138	1 116					
11 G C.	936	.781						
12 L P	1 237	1 299	1.225	1 314	1.298	1.271	1.246	
13 E S.	1 213	1 311	1.275	1 265	1 224	1 282	1.216	1 206
14 S G	965	902	.896	.971				
15 N G.	749	.732	766	.740	.755			
16 Å D.	1 110	993	.982					
17 R J.	645	.630	666	.700				
18 Å B	647	651	642	681	666			
19 S K.	1 489							
20 H M	538							
21 H H	1 116							
22 A C.	978							
23 L H	—							
24 B O	—							
25 J A	—							
26 E.J	—							
Female cases								
27 I S	722	,693	759					
28 V G	797	,721	750					
29 V L.	574	632	640					
30 M N.	553	599	538					
31 K E	411	405	.376	.407	408			
32 U K	481	456						
33 C.S	514	469	434	460				
34 K Å	445	447	.495	.463	.463			
35 A L.	652							
36 K W	640							
37 V N.	—							
38 F R	—							
39 A.B	—							
40 B H	—							
41 M.Z.	666	722						

Male cases:

Source of variation	Degrees of freedom	Mean square
Case	12	0 2443
Determination[a]	40	0 0016

[a]Relative error for a single determination $100(0\ 0016)^{1/2}/0.94 = \pm 4$ per cent

Female cases:

Source of variation	Degrees of freedom	Mean square
Case	8	0 0577
Determination[a]	21	0 0174

[a]Relative error for a single determination $100(0\ 0174)^{1/2}/0.58 \approx \pm 5$ per cent

TABLE 8 *Recorded deflection for a load of 5 kgf on the intact tibia. (Cases with two or more values are used for the analysis of variance.)*

		Recorded deflection, microns									
Male cases											
1	L.H.	92	98	95							
2	H.W.	107	109	104							
3	S.S.	80	80	86	87	86					
4	L.B.	75	71	76	82						
5	K.F.	83	76	80	71	87					
6	L.L.	104	83	93	114						
7	F.S.	93	78	93							
8	N.S.	124	132	110	109						
9	G.W.	118	120	106	106						
10	G.S.	81	88	84	90						
11	G.C.	84	100	96							
12	L.P.	75	70	82	93	98	92	95	86	97	90
13	E.S.	86	96	91	90	96	87	79	89		
14	S.G.	88	95	86	94						
15	N.G.	117	130	131	131	122					
16	A.D.	94	93	86							
17	R.J.	122	121	117	117						
18	A.B.	(136)	107	117	124	111					
19	S.K.	68									
20	H.M.	145									
21	H.H.	137									
22	A.C.	105									
23	L.H.	85									
24	B.O.	54									
25	I.A.	86	93								
26	E.J.	90									
Female cases											
27	I.S.	130	125	130							
28	V.G.	135	132	141							
29	V.L.	116	111	110	113	116	132				
30	M.N.	123	124	117							
31	K.E.	158	179	189	176	183					
32	U.K.	139	143								
33	C.S.	167	175	194	168						
34	K.A.	(133)	159	168	165	162					
35	A.L.	138									
36	K.W.	124									
37	V.N.	175	225								
38	E.R.	143	130								
39	A.B.	96									
40	B.H.	155									
41	M.Z.	(111)	147	157							

Male cases:

	Degrees of freedom	Mean square
Source of variation		
Case	18	951
Measurement[a]	62	23

[a]Relative error for a single measurement $100(23)^{1/2}/97 = \pm 5$ per cent

Female cases:

	Degrees of freedom	Mean square
Source of variation		
Case	10	2382
Measurement[a]	25	146

[a]Relative error for a single measurement $100(146)^{1/2}/149 = \pm 8$ per cent

tion (*Snedecor & Cochran*, Chapter 12). There was no significant difference between the right and left sides. The estimated relative error for a single measurement was ±5 per cent. With the constant 1/67, E was obtained as 2.0×10^3 kgf/mm².

Discussion

Measurements on the tibia *intra vitam* differ in a number of respects from those on autopsy specimens. There are several factors that can have a bearing on the magnitude of the deflection.

The living tibia is exposed to the mechanical effects of the surrounding tissues, has a higher water content and is perfused with blood, which is under pressure. The effect of these factors, together with the temperature, burdens the relative errors for the single measurements of the deflection and the moment of inertia.

The deflection is influenced by the temperature, it being greater for the warmer tibia than for the autopsy specimens. In a study of the modulus of elasticity of bone in bending Sedlin (1965) found a 6 per cent lower value at 37 than at 21°C; the difference was statistically significant. This result is consistent with those reported by Smith & Walmsley (1959), who found that the elasticity modulus is inversely related to the temperature of the bone specimen.

Unlike the specimen the vital tibia has a constant water content. It has been reported that a short period of exposure of a bone specimen to a room atmosphere is enough to increase the modulus of elesticity of bone; Smith & Walsley (1959) recorded an increase of 7 per cent after one hour; however, for a period of 10 minutes Sedlin (1965) found no change.

The presence of an intact fibula has an effect on the deflection of the tibia. This was tested as follows: The deflection of the tibia on autopsy specimens was registered with the instrument. With this still in place the fibula was sawn off at the level of the middle pin. The values of the deflec-

TABLE 11 *Analysis of variance for the deflection of the tibia before and after resection of the fibula*

	Degrees of freedom	Mean square	F ratio	P
Source of variation				
Specimen	12	3210		
Resection	1	30	$F_{1,12} = 5.45$	0.05>0.01
Error and interaction	12	5.5		

The modulus of elasticity of the sound tibia

From the means of the observed deflection and moment of inertia the apparent modulus of elasticity for the men and women were calculated, namely 2.65×10^3 and 2.3×10^3 kgf/mm², respectively; with the constant 1/67 the corresponding values of E are 1.9×10^3 and 1.6×10^3 kgf/mm².

The determined error in the observed deflection is the same in the corrected deflection after subtraction of the systematic error of the method. When the relative error of the corrected deflection was calculated and since the relative error in the moment of inertia was known, the relative error of the modulus of elasticity was obtained from the square root of the sum of the squares of the relative errors in the measurement of the deflection and the moment of inertia; it was ±9 and ±12 per cent for men and women, respectively.

The modulus of elasticity of the tibia in controls

When one tibia is fractured the other one cannot be regarded as completely normal, but may be expected to display changes such as a measure of osteoporosis. It was accordingly considered of interest to perform measurements on normal tibias *intra vitam*. The apparent modulus of elasticity was determined on both tibias in 9 voluntary subjects in sound health and with no history of leg injury. Their mean age was 25 years (range 22—31). The values of the apparent modulus of elasticity ("E") and the corresponding analysis of variance are given in table 10. The observed values constitute a 2-factor experiment with the subject and the side as sources of varia-

TABLE 10 *Analysis of variance for the apparent modulus of elasticity for both tibias in male subjects 22–31 years of age.*

	Apparent modulus of elasticity, kgf/cm²								
Case	1	2	3	4	5	6	7	8	9
Right	361,277	311,277	307,927	220,065	267,354	274,494	277,031	290,208	232,465
Left	328,747	326,531	302,111	204,195	224,523	260,339	276,369	301,676	232,727

	Degrees of freedom	Mean square $\times 10^6$	F ratio	P
Source of variation				
Subject	8	3689		
Side	1	397	$F_{1,8} = 2.15$	>0.05
Error and interaction*	8	185		

*Relative error for a single determination $100(185 \times 10^6)^{1/2}/277{,}000 = \pm 5$ per cent

CLINICAL INVESTIGATION

In this section the patients on whom the stability measurements were performed are presented. The relevant data constitute the basis for the evalution of the principle and the method for assessing the stability of healing fracture of the tibia.

The values for the deflection of the fractured tibia were examined as regards their correlation with time and the clinical findings and results.

Measurements on the fractured tibia were not performed until the callus had become resilient. Only in the first case (no. 25) were registrations performed while the fracture were quite unstable. The information yielded by the recorded curves was of little value for two reasons: firstly, the clinical findings relating to the stability were reliable and, secondly, the load-deflection curve is easily influenced by the weight of the very mobile fracture fragments which loads the force transducer.

The deflections recorded for a load of 5 kgf on the fractured tibia, v_{tot}, and the intact tibia, v_i, at various intervals after fracture are presented in table 12 (page 73), together with the calculated quotient s/E_f or s/E_fI_f. The deflections of both tibias are also presented in graphs with the following case reports.

Case reports

CASE 1 L.H. Bricklayer, 20 years; upper half of the tibia fractured in a road accident. Long leg cast for 22 weeks at another hospital; during last few weeks partial weight bearing, one crutch. *Twenty-two weeks* —Responsible surgeon doubtful whether cast might be removed; fracture nearly stable. Radiographs showed distinct callus but fracture line clearly visible. Deflection 0.172 mm, $s/E_f = 0.44$. No cast, gradual weight bearing recommended. *Twenty-eight weeks* —Had used a crutch outdoors but full weight bearing indoors. Fracture clinically stable; deflection 0.138 mm, $s/E_f = 0.23$. *Thirty-four weeks.*—Full weight bearing also outdoors. Deflection 0.128 mm, $s/E_f = 0.18$. Returned a month later because of occasional falls, but the fractured leg had given no trouble. Radiographs: increased amount of callus, fracture line less clear.

CASE 2 H.W. Lorry driver, 25 years; spiral fracture of tibia from falling downstairs. Long leg cast at another hospital. *Eight weeks.*—Fracture clinically unstable. Radiographs: Loose callus; large parts of the fracture line visible. Deflection 0.282 mm; $s/E_f = 0.36$. Walking boot cast; weight bearing recommended. *Thirteen weeks.*—Fracture clini-

tion after and before resection of the fibula were examined by analysis of variance. They constitued a 2-factor experiment with subject and resection as sources of variation (*Snedecor & Cochran*, Chapter 12). The analysis showed an almost significant increase in the deflection after resection (Table 11). This increase was on average 2 per cent of the deflection before resection.

If the modulus of elasticity of the sound tibia varies during the course of the investigation, there will be an increase in the error for the reproduced values of deflection. To judge from the observed deflection of the sound tibia, there was no such variation.

The effect on the deflection of varying distance from the middle pin to the narrowest part of the sound tibia was tested on each patient separately. Where there were at least two observations the slope of the regression line was determined by the method of least squares, with the deflection on the axis of y and the distance of the middle pin from the narrowest part of the tibia on the axis of x. The regression coefficient was negative in 15 cases and positive in 7 but there was no statistically significant deviation from the horizontal position of the line. The fact that in the measurements an attempt was made to obtain a constant value of x might explain why the sign test was not significant.

No explanation of the difference in the relative error in the deflection for women and men can be offered, unless it might be ascribed to the greater difficulty in obtaining a firm hold for pins in women over 50 years, possibly because of osteoporosis and a thinner cortical layer.

In the experiments on the autopsy specimens from women it also seemed to be more difficult to fix the pins in the case of the pin distance of 24 cm. This may have been due to the tendency for the tibia to be shorter in the women than the men, with respective averages of 34 and 38 cm. Thus, a pin distance of 21 cm would presumably be more suitable for measurements on the female tibia.

It is obviously more difficult to determine the midline on the medial surface of the tibia *intra vitam*, but otherwise the experimental conditions, with the mentioned exceptions, were much the same as for the autopsy specimen; the views concerning measurements on the specimens presented in the *Discussion* also apply to the tibia *intra vitam*.

The reproducibility of the approximate moment of inertia was acceptable. It would be difficult to attain a higher accuracy without making the radiologic examination much more time-consuming, but, as said before (page 15), a determination of the moment on some more levels of the tibia would give a more reliable value of the moment of inertia of the tibia.

CLINICAL INVESTIGATION

In this section the patients on whom the stability measurements were performed are presented. The relevant data constitute the basis for the evalution of the principle and the method for assessing the stability of healing fracture of the tibia.

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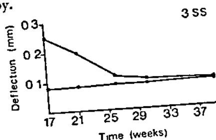
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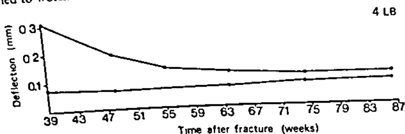
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Radiographs: increased callus. Unwilling to return to strenuous work. *Thirty-nine weeks.*—Deflection 0.095 mm, $s/E_f=0.02$ mm. Referred for occupational therapy.

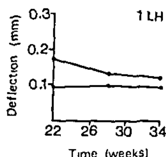


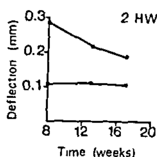
CASE 4 L.B. Stores supervisor, 58 years; spiral fracture of tibia through fall in snow. Long leg cast. *Thirty-nine weeks.*— Fracture almost stable. Radiographs: incipient callus. Deflection 0.308 mm, $s/E_f=0.29$. Long walking boot cast, gradual weight bearing advised. *Forty-eight weeks.*—Fracture loaded in the cast without trouble. Radiographs: incipient consolidation, but large parts of the fracture line still visualized. Fracture clinically almost stable. Deflection 0.192 mm, $s/E_f=0.14$. Cast not removed and increased weight bearing, one crutch. *Fifty-five weeks.*—Fracture clinically stable. Radiographic appearances unchanged. Deflection 0.140 mm, $s/E_f=0.08$. Cast removed, gradual weight bearing. *Sixty-four weeks*—Full weight bearing, union regarded as complete. Deflection 0.119 mm, $s/E_f=0.06$. *Seventy-four weeks.*—Deflection 0.106 mm, $s/E_f=0.04$ mm. *Eighty-six weeks*—Deflection 0.116 mm, $s/E_f=0.05$. Returned to work.



CASE 5 K.F. Clerk, 22 years; transverse fracture of upper third of tibia caused by a kick received during football. Long leg cast. *Six weeks.*—Clinically unstable. Radiographs: very loose incipient callus. Deflection 0.882 mm, $s/E_f=2.04$. *Eleven weeks.*—Fracture unstable. Radiographs: callus forming a bridge in front, but at back loose. Deflection

cally stable. Radiographs: increasing callus. Deflection 0.217 mm, s/E_f= 0.19. Walking boot cast continued, increased weight bearing advised. *Seventeen weeks.*—Deflection 0.190 mm, s/E_f=0.15. Full weight bearing continued, no cast. Fracture regarded as united, fulltime work resumed a few weeks later.



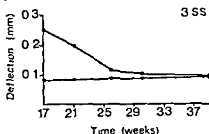


CASE 3 S.S. General labourer, 53 years; proximal and distal fractures of tibia with 14 cm long middle fragment, result of road accident (Fig. 14). Long leg cast. *Seventeen weeks.*—Two crutches; slight tenderness over the distal fracture. Fracture almost stable; deflection 0.249 mm, s/E_f=0.27, calculated only for lower fracture, upper one regarded as stable. Walking boot cast, two crutches, gradual weight bearing advised. *Twenty-one weeks.*—Because of pain no increased weight bearing. Radiographs: increasing callus. Deflection 0.193 mm, s/E_f=0.18. Walking boot cast, one crutch. *Twenty-seven weeks.*—Deflection 0.118 mm, s/E_f=0.06. *Thirty-one weeks.*—Had used two crutches, but occasionally full bearing. Deflection 0.098 mm, s/E_f=0.02. Union regarded as complete.

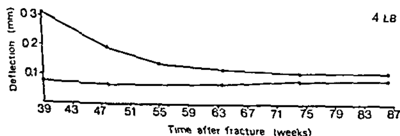


FIGURE 14 *Radiographs of fractured tibia taken 17—39 weeks after the fracture.* Case 3 S.S

Radiographs: increased callus. Unwilling to return to strenuous work. *Thirty-nine weeks.*—Deflection 0.095 mm, s/E_f=0.02 mm. Referred for occupational therapy.

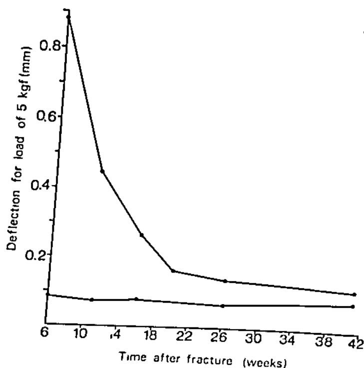


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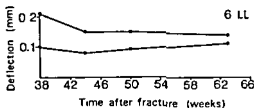
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0.450 mm, s/E_f=0.94. Long walking boot cast, gradual weight bearing advised. *Sixteen weeks.*—Fracture almost stable. Radiographs: increased callus, but fracture line distinctly visualized. Deflection 0.278 mm, s/E_f=0.50. Two crutches without the cast; gradual weight bearing advised. *Twenty weeks.*—Fracture clinically stable. Radiographs: unchanged callus. Deflection by extrapolation 0.170* mm, s/E_f=0.22. One crutch recommended. *Twenty-six weeks.*—Patient had used one crutch outdoors and full weight bearing indoors. Radiographs: unchanged callus. Deflection 0.148 mm, s/E_f=0.17. Fracture considered to be united; returned to work 6 weeks later. *Forty-one weeks.*—Radiographs showed increased callus. No complaints. Deflection 0.129 mm, s/E_f=0.13.

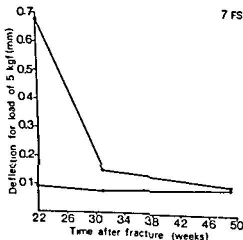


CASE 6 L.L. Stores supervisor, 43 years; short oblique fracture of tibia from road accident. Long leg cast. Repeated radiographic examinations had shown no increase in callus. Patient referred to this hospital for operation to hasten healing. *Thirty-eight weeks.*—Fracture clinically almost stable. Radiographs: callus laterally via an intermediate fragment. Deflection 0.209 mm, s/E_f=0.21. Decided to await result of further examination before deciding on operation to accelerate union. Cast removed; two crutches increasing weight bearing. *Forty-four weeks.*—Had walked up to 1 km a day with one crutch. Fracture clinically stable. Radiographs:

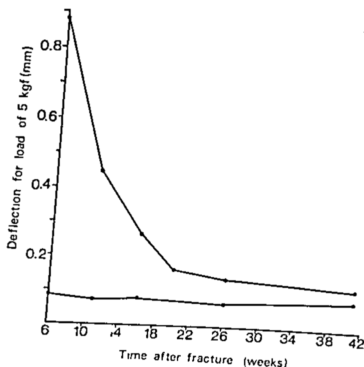
evident callus on the lateral aspect, almost none medially, large parts of the fracture line visualized. Deflection 0.150 mm, s/E_f=0.08. *Fifty weeks.* —After full weight bearing, no trouble. Radiographs: unchanged callus. Deflection 0.147 mm, s/E_f=0.08. Full-time work resumed after 6 weeks. *Sixty-three weeks.*—Deflection 0.143 mm, s/E_f=0.07.



CASE 7 F.S. Student, 20 years; open transverse fracture of tibia due to an explosion. Extension treatment 4 weeks; long leg cast 12 weeks. Walking with two crutches but no weight on leg. Because of slow union, attending surgeon at another hospital proposed operation to hasten healing. *Twenty-two weeks.*—Fracture clinically unstable. Radiographs: callus bridge on lateral and posterior aspects; callus less marked on anterolateral aspect but no sclerotic change in fragment ends as in pseudarthrosis. Deflection 0.680 mm, s/E_f=0.79. Walking boot cast; careful weight bearing advised. *Thirty-one weeks*—Fracture clinically stable. Deflection 0.150 mm, s/E_f=0.08. No cast, crutches withdrawn. *Forty-nine weeks.*—Full weight bearing. Radiographs: full consolidation. Deflection 0.104 mm, s/E_f=0.02.

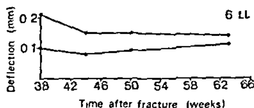


0.450 mm, s/E_f=0.94. Long walking boot cast, gradual weight bearing advised. *Sixteen weeks.*—Fracture almost stable. Radiographs: increased callus, but fracture line distinctly visualized. Deflection 0.278 mm, s/E_f=0.50. Two crutches without the cast; gradual weight bearing advised. *Twenty weeks.*—Fracture clinically stable. Radiographs: unchanged callus. Deflection by extrapolation 0.170 mm, s/E_f=0.22. One crutch recommended. *Twenty-six weeks.*—Patient had used one crutch outdoors and full weight bearing indoors. Radiographs: unchanged callus. Deflection 0.148 mm, s/E_f=0.17. Fracture considered to be united; returned to work 6 weeks later. *Forty-one weeks.*—Radiographs showed increased callus. No complaints. Deflection 0.129 mm, s/E_f=0.13.

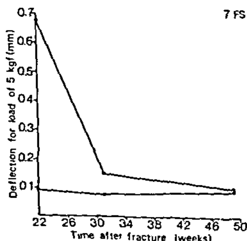


CASE 6 L.L. Stores supervisor, 43 years; short oblique fracture of tibia from road accident. Long leg cast. Repeated radiographic examinations had shown no increase in callus. Patient referred to this hospital for operation to hasten healing. *Thirty-eight weeks.*—Fracture clinically almost stable. Radiographs: callus laterally via an intermediate fragment. Deflection 0.209 mm, s/E_f=0.21. Decided to await result of further examination before deciding on operation to accelerate union. Cast removed; two crutches increasing weight bearing. *Forty-four weeks.*—Had walked up to 1 km a day with one crutch. Fracture clinically stable. Radiographs:

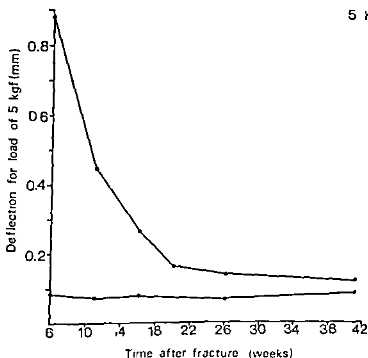
lent callus on the lateral aspect, almost none medially, large parts of fracture line visualized. Deflection 0.150 mm, $s/E_f=0.08$. *Fifty weeks.* :After full weight bearing, no trouble. Radiographs: unchanged callus. :lection 0.147 mm, $s/E_f=0.08$. Full-time work resumed after 6 weeks. *ty-three weeks.*—Deflection 0.143 mm, $s/E_f=0.07$.



ASE 7 F.S. Student, 20 years; open transverse fracture of tibia due to an explosion. Extension treatment 4 weeks; long leg cast weeks. Walking with two crutches but no weight on leg. Because of w union, attending surgeon at another hospital proposed operation to sten healing. *Twenty-two weeks.*—Fracture clinically unstable. Radio-aphs: callus bridge on lateral and posterior aspects; callus less marked anterolateral aspect but no sclerotic change in fragment ends as in pseud-throsis. Deflection 0.680 mm, $s/E_f=0.79$. Walking boot cast; careful eight bearing advised. *Thirty-one weeks.*—Fracture clinically stable. De-ection 0.150 mm, $s/E_f=0.08$. No cast, crutches withdrawn. *Forty-nine eeks.*—Full weight bearing. Radiographs: full consolidation. Deflection 104 mm, $s/E_f=0.02$.

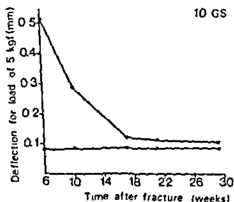


0.450 mm, s/E_f=0.94. Long walking boot cast, gradual weight bearing advised. *Sixteen weeks.*—Fracture almost stable. Radiographs: increased callus, but fracture line distinctly visualized. Deflection 0.278 mm, s/E_f=0.50. Two crutches without the cast; gradual weight bearing advised. *Twenty weeks.*—Fracture clinically stable. Radiographs: unchanged callus. Deflection by extrapolation 0.170* mm, s/E_f=0.22. One crutch recommended. *Twenty-six weeks.*—Patient had used one crutch outdoors and full weight bearing indoors. Radiographs: unchanged callus. Deflection 0.148 mm, s/E_f=0.17. Fracture considered to be united; returned to work 6 weeks later. *Forty-one weeks.*—Radiographs showed increased callus. No complaints. Deflection 0.129 mm, s/E_f=0.13.

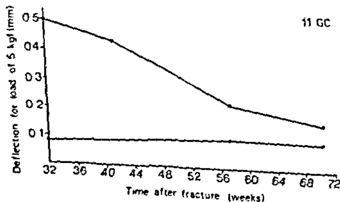


CASE 6 L.L. Stores supervisor, 43 years; short oblique fracture of tibia from road accident. Long leg cast. Repeated radiographic examinations had shown no increase in callus. Patient referred to this hospital for operation to hasten healing. *Thirty-eight weeks.*—Fracture clinically almost stable. Radiographs: callus laterally via an intermediate fragment. Deflection 0.209 mm, s/E_f=0.21. Decided to await result of further examination before deciding on operation to accelerate union. Cast removed; two crutches increasing weight bearing. *Forty-four weeks.*—Had walked up to 1 km a day with one crutch. Fracture clinically stable. Radiographs:

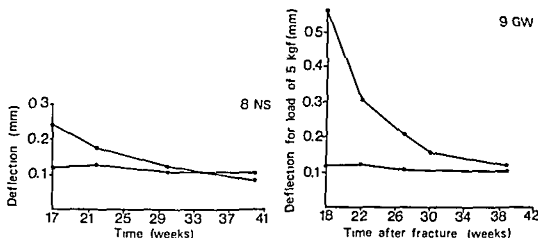
CASE 10 G.S. Driver, 53 years; open fracture of tibia. Long leg cast. *Six weeks.*—*Clinically unstable. Radiographs: no visible* callus. Deflection 0.510 mm, s/E_f=1.13. New cast. *Ten weeks.*—Clinically almost stable. Radiographs: incipient callus. Deflection 0.290 mm, s/E_f=0.85. Walking boot cast. Partial weight bearing. *Sixteen weeks.*—*Fracture clinically stable.* Radiographs: increased callus. Deflection 0.120 mm, s/E_f=0.18. *Twenty weeks.*—Radiographs: unchanged callus. Deflection 0.113 mm, s/E_f=0.15 . No cast, gradual weight bearing, two crutches for 4 weeks, then one crutch. *Twenty-nine weeks.*—Full weight bearing. Radiographs: increasing consolidation. Deflection 0.106 mm, s/E_f=0.11. Full-time work resumed 2 weeks later.



CASE 11 G.C. Engineer, 26 years; fractured tibia during skiing. Cast, delayed union. Eleven months.—Operation at another hospital, unsuccessful; twenty months new operation, sliding inlay graft; long leg cast for 7 months. Partial weight bearing with cast. Radiographs:



CASE 8 N.S. Student, 17 years; open distal fracture of tibia from falling tree. Fracture transfixed by two screws; long leg cast; eleven weeks later short leg cast. *Seventeen weeks.*—Fracture clinically stable. Radiographs: incipient bridging by loose callus. Deflection 0.246 mm, $s/E_fI_f = 0.13$. Increased weight bearing advised. *Twenty-two weeks.*—Radiographs: increase in callus. Deflection 0.180 mm, $s/E_fI_f = 0.06$. No cast, increased weight bearing; after 3 weeks, one crutch. *Thirty weeks.*—Full weight bearing. Radiographs: increasing callus. Deflection 0.130 mm, $s/E_fI_f = 0.01$. *Forty weeks.*—Patient fully active. Radiographs: full consolidation. Deflection 0.99 mm, $s/E_fI_f < 0$.



CASE 9 G.W. Student, 21 years; tibia fractured distally during vacation work. Fixation with medullary Küntscher nail, removed one month later because of proximal slipping. Long leg cast. *Eighteen weeks.*—Fracture clinically unstable. Radiographs: minimal, loose callus. Deflection 0.560 mm, $s/E_fI_f = 1.10$. New cast. *Twenty-two weeks.*—fracture clinically stable. Radiographs: increased callus, but much of the fracture gap visualized. Deflection 0.305 mm, $s/E_fI_f = 0.53$. No cast, gradual weight bearing; two crutches advised. *Twenty-seven weeks*—Further stabilization. Radiographs: increased bridging callus, but fracture line still visible. Deflection 0.212 mm, $s/E_fI_f = 0.24$. Increased weight bearing with only one crutch a week or two, then full weight bearing. *Thirty weeks.*—Deflection 0.160 mm, $s/E_fI_f = 0.12$. *Thirty-nine weeks.*—Walks, full weight bearing, no trouble. Radiographs: increased callus, bridging on the lateral aspect. Deflection 0.125 mm, $s/E_fI_f = 0.03$. Fracture regarded as united.

12 LP

Deflection for load of 5 kgf (mm)

0.8
0.6
0.4
0.2

1 10 13 34 38 42 46 50 54 58 62 66 70 74 78 82

Time after fracture (weeks)

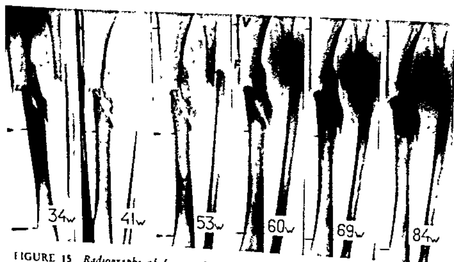


FIGURE 15 *Radiographs of fractured tibia taken 34—84 weeks after fracture* Case 12 L P

fracture of graft. Attending surgeon discussed further operation. *Thirty-two weeks* after latest operation.—Fracture unstable. Deflection 0.500 mm, s/E_f=0.36. Two crutches gradual weight bearing. *Forty-one weeks.*—For some weeks, one crutch. Radiographs: no change in callus. Fracture unstable. Deflection 0.430 mm, s/E_f=0.29. Continued with one crutch for a month, then full weight bearing. *Fifty-seven weeks.*—Fracture clinically stable. Radiographs: slight increase of callus. Deflection 0.218 mm, s/E_f=0.13. After a month work resumed. No residual symptoms. *Seventy weeks.*—Deflection 0.162 mm, s/E_f=0.06.

CASE 12 L.P. Carpenter, 44 years; fracture of proximal half of tibia in road accident. Extension, transfixed long leg cast. Sound tibia measured after *one week.*—Deflection 0.075 mm. *Ten weeks.*—Cast renewed. Fracture too unstable for measurement. Sound tibia, deflection 0.070 mm. *Thirteen weeks.*—Likewise; fracture unstable. Radiographs: large fracture gap. Sound tibia, deflection 0.084 mm. Operation to hasten union considered, but patient preferred to continue with cast. Eight months after fracture, instability persisted but careful loading of leg in a long leg cast permitted. *Thirty-four weeks.*—Fracture unstable. Radiographs: slight increase of callus from negligible (Fig. 15). Deflection 0.880 mm, s/E_f= 1.75. Long walking boot cast, gradual weight bearing continued. *Forty-one weeks.*—Clinically unstable. Radiographs: no change. Deflection 0.530 mm, s/E_f=0.96. New cast. *Forty-seven weeks.*—Clinically unstable. Radiographs unchanged. Deflection 0.392 mm, s/E_f=0.67. Because the middle pin loosened, radiographs were taken without pins in place. Considerable stiffness in the knee and ankle owing to the long period of immobilization; cast removed. Two crutches; instructed to put weight on leg carefully; despite this warning, had sometimes put full weight on the leg though without pain or aching. *Fifty-three weeks.*—Fracture unstable. Radiographs: unchanged callus. Deflection 0.493 mm, s/E_f=0.88. Because of this increase and to prevent development of pseudarthrosis, use of knee cast. Partial weight bearing permitted, but with two crutches. *Sixty weeks.*—Fracture unstable. Deflection 0.250 mm, s/E_f=0.35. Knee cast continued, increased weight bearing. *Sixty-nine weeks.*—Occasional full weight bearing, no pain. Fracture clinically stable. Radiographs: increase in callus. Deflection 0.226 mm, s/E_f=0.30. Cast removed, one crutch withdrawn two weeks before last measurement. *Eighty-four weeks.*—Knee mobility 180—80°, ankle 75—135°. Circumference of the thigh 1 cm less on side of fracture. Deflection 0.127 mm, s/E_f=0.07. One month later full-time work resumed. Union complete; no residual disability.

tibia, deflection 0.086 mm. *Fourteen weeks.*—Fracture still quite unstable. Radiographs: no evidence of consolidation (Fig. 16); corresponding original load-deflection curves representing course of healing in figure 17. Deflection 1.210 mm, $s/E_f=1.55$. *Twenty-one weeks.*—No change; deflection 1.200 mm, $s/E_f=1.57$. *Twenty-five weeks.*—Fracture unstable. Radio-

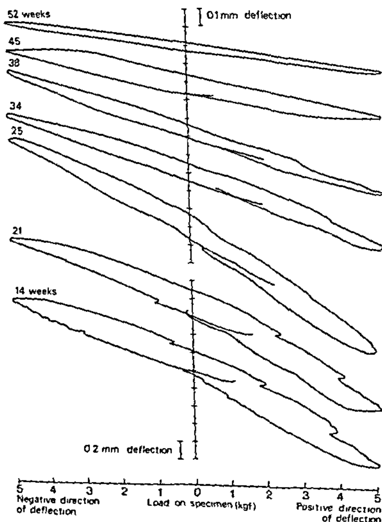


FIGURE 17 *Load-deflection curves for fractured tibia taken 14—52 weeks after fracture. Case 13 L S*

Note that in the curves 14 and 21 weeks after fracture the scale for deflection is different from that for the other curves

CASE 13 E.S. Smith, 66 years; retired on sick pension. Involved in road accident. Treated at another hospital for skull fracture, concussion, delirium tremens and fracture of tibia. Long leg cast. *Eleven weeks.*—When cast changed, fracture too unstable to be measured. Sound

13 ES

Deflection for load of 5 kgf (mm)

12 10 08 06 04 02

8 12 16 20 24 28 32 36 40 44 48 52

Time after fracture (weeks)

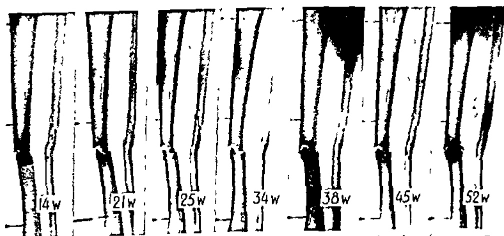


FIGURE 16 *Radiographs of fractured tibia taken 14—52 weeks after fracture. Case 13 E S.*

tibia, deflection 0.086 mm. *Fourteen weeks.*—Fracture still quite unstable. Radiographs: no evidence of consolidation (Fig. 16); corresponding original load-deflection curves representing course of healing in figure 17. Deflection 1.210 mm, $s/E_f = 1.55$. *Twenty-one weeks.*—No change; deflection 1.200 mm, $s/E_f = 1.57$. *Twenty-five weeks.*—Fracture unstable. Radio-

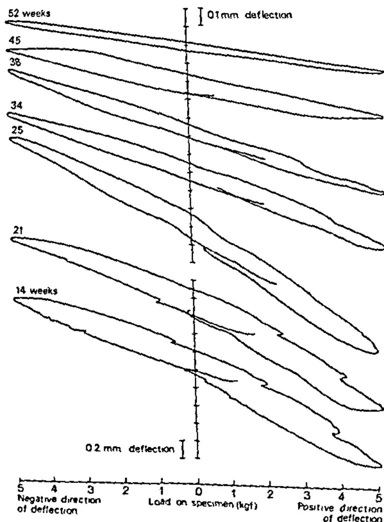
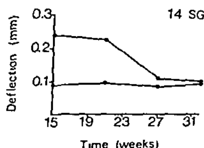


FIGURE 17 *Load-deflection curves for fractured tibia taken 14—52 weeks after fracture* Case 13 F S

Note that in the curves 14 and 21 weeks after fracture the scale for deflection is different from that for the other curves

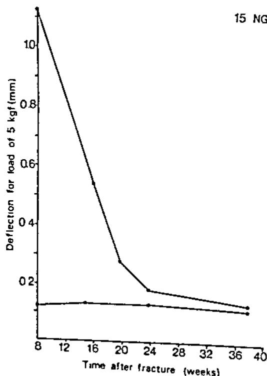
graphs unchanged. Deflection 0.718 mm, s/E_f=0.90. Long walking boot cast. Gradual weight bearing. *Thirty-four weeks.*—Fracture unstable. Radiographs: slight callus on anterior aspect. Deflection 0.446 mm, s/E_f=0.49. Patellar-tendon-bearing (PTB) cast; two crutches and gradual weight bearing. *Thirty-eight weeks.*—Clinically almost stable. Deflection 0.376 mm, s/E_f=0.41. Continued PTB cast, increased weight bearing. *Forty-five weeks.*—One crutch, occasionally full weight bearing; fracture stable. Radiographs: increase in callus. Deflection 0.222 mm, s/E_f=0.19. Increased weight bearing without cast advised. *Fifty-two weeks.*—A year after accident, full weight bearing, slight limp because of pain in the ankle. Knee mobility 180—90° ankle 85—120°. Deflection 0.149 mm, s/E_f=0.08. Fracture considered united. Radiographs showed consolidation.

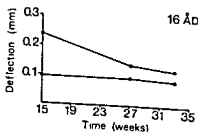
CASE 14 S.G. Building worker, 47 years; fractured tibia in a fall in street. Transfixion and long leg cast. *Fifteen weeks.*—Fracture unstable. Radiographs: no callus. Deflection 0.243 mm, s/E_f=0.41. PTB cast, partial weight bearing. *Twenty-one weeks.*—Fracture almost stable, clinically. Radiographs: no definite bridging by callus; fracture line clearly visible. Deflection 0.222 mm, s/E_f=0.26. Tenderness around fracture. Cast retained. *Twenty-seven weeks.*—Clinically stable. Radiographs: fracture line still evident, but callus increased. Deflection 0.110 mm, s/E_f=0.06. No cast; gradual weight bearing, at first two crutches. *Thirty-two weeks.*—Fracture regarded as clinically healed. Radiographs: increase of callus, but much of fracture line visualized. Deflection 0.100 mm, s/E_f=0.02.



CASE 15 N.G. Draughtsman, 20 years; fractured tibia during skiing. Long leg cast. *Eight weeks*—Clinically unstable. Radiographs: loose callus. Deflection 1.120 mm, s/E_f=1.92. PTB cast; two crutches. *Fifteen weeks.*—Fracture unstable. Radiographs: increase of callus. Deflection 0.540 mm, s/E_f=0.73. *Twenty weeks.*—Weight bearing gradu-

ally increased, occasional full weight bearing for a few steps. Fracture almost stable clinically. Deflection 0.278 mm, $s/E_f=0.25$. Exercise mobility; first with two crutches, later one, without cast. *Twenty-four weeks.*—Last seven days, full weight bearing. Walks of up to 90 min. Fracture regarded as healed. Deflection 0.186 mm, $s/E_f=0.10$. *Thirty-eight weeks.*—No residual symtoms. Deflection 0.139 mm, $s/E_f=0.02$.

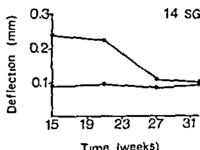




CASE 16 Å.D. Typographer, 35 years; fractured tibia in fall. Long leg cast. *Fifteen weeks.*—Clinically unstable. Radiographs: loose callus and clearly visualized fracture gap. Deflection 0.234 mm, $s/E_f=0.63$. Same day, open reduction and transfixion of fracture with AO screws and long leg cast. *Twenty-seven weeks.*—Fracture clinically stable. Radiographs: good callus. Deflection 0.136 mm, $s/E_f=0.18$. Cast removed; gradual weight bearing. *Thirty-three weeks.*—Full weight bearing; no residual trouble. Radiographs: consolidation. Deflection 0.119 mm, $s/E_f=$ 0.11. Fracture regarded as healed.

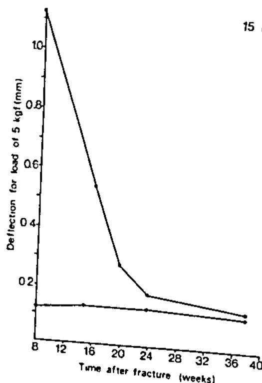
graphs unchanged. Deflection 0.718 mm, $s/E_f = 0.90$. Long walking boot cast. Gradual weight bearing. *Thirty-four weeks.*—Fracture unstable. Radiographs: slight callus on anterior aspect. Deflection 0.446 mm, $s/E_f = 0.49$. Patellar-tendon-bearing (PTB) cast; two crutches and gradual weight bearing. *Thirty-eight weeks.*—Clinically almost stable. Deflection 0.376 mm, $s/E_f = 0.41$. Continued PTB cast, increased weight bearing. *Forty-five weeks.*—One crutch, occasionally full weight bearing; fracture stable. Radiographs: increase in callus. Deflection 0.222 mm, $s/E_f = 0.19$. Increased weight bearing without cast advised. *Fifty-two weeks.*—A year after accident, full weight bearing, slight limp because of pain in the ankle. Knee mobility 180—90° ankle 85—120°. Deflection 0.149 mm, $s/E_f = 0.08$. Fracture considered united. Radiographs showed consolidation.

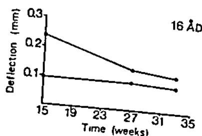
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CASE 15 N.G. Draughtsman, 20 years; fractured tibia during skiing. Long leg cast. *Eight weeks.*—Clinically unstable. Radiographs: loose callus. Deflection 1.120 mm, $s/E_f = 1.92$. PTB cast; two crutches. *Fifteen weeks.*—Fracture unstable. Radiographs: increase of callus. Deflection 0.540 mm, $s/E_f = 0.73$. *Twenty weeks.*—Weight bearing gradu-

ally increased, occasional full weight bearing for a few steps. Fracture almost stable clinically. Deflection 0.278 mm, $s/E_f=0.25$. Exercise mobility; first with two crutches, later one, without cast. *Twenty-four weeks.*—Last seven days, full weight bearing. Walks of up to 90 min. Fracture regarded as healed. Deflection 0.186 mm, $s/E_f=0.10$. *Thirty-eight weeks.*—No residual symtoms. Deflection 0.139 mm, $s/E_f=0.02$.

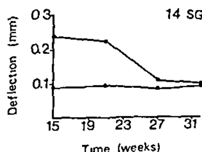




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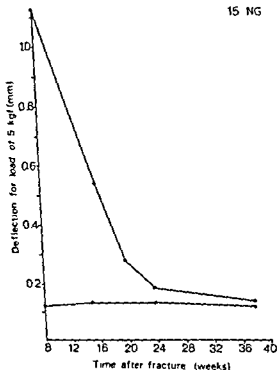
graphs unchanged. Deflection 0.718 mm, $s/E_f=0.90$. Long walking boot cast. Gradual weight bearing. *Thirty-four weeks.*—Fracture unstable. Radiographs: slight callus on anterior aspect. Deflection 0.446 mm, $s/E_f=0.49$. Patellar-tendon-bearing (PTB) cast; two crutches and gradual weight bearing. *Thirty-eight weeks.*—Clinically almost stable. Deflection 0.376 mm, $s/E_f=0.41$. Continued PTB cast, increased weight bearing. *Forty-five weeks.*—One crutch, occasionally full weight bearing; fracture stable. Radiographs: increase in callus. Deflection 0.222 mm, $s/E_f=0.19$. Increased weight bearing without cast advised. *Fifty-two weeks.*—A year after accident, full weight bearing, slight limp because of pain in the ankle. Knee mobility 180—90° ankle 85—120°. Deflection 0.149 mm, $s/E_f=0.08$. Fracture considered united. Radiographs showed consolidation.

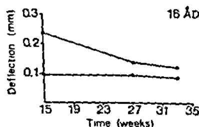
CASE 14 S.G. Building worker, 47 years; fractured tibia in a fall in street. Transfixion and long leg cast. *Fifteen weeks.*—Fracture unstable. Radiographs: no callus. Deflection 0.243 mm, $s/E_f=0.41$. PTB cast, partial weight bearing. *Twenty-one weeks.*—Fracture almost stable, clinically. Radiographs: no definite bridging by callus; fracture line clearly visible. Deflection 0.222 mm, $s/E_f=0.26$. Tenderness around fracture. Cast retained. *Twenty-seven weeks.*—Clinically stable. Radiographs: fracture line still evident, but callus increased. Deflection 0.110 mm, $s/E_f=0.06$. No cast; gradual weight bearing, at first two crutches. *Thirty-two weeks.*—Fracture regarded as clinically healed. Radiographs: increase of callus, but much of fracture line visualized. Deflection 0.100 mm, $s/E_f=0.02$.



CASE 15 N.G. Draughtsman, 20 years; fractured tibia during skiing. Long leg cast. *Eight weeks.*—Clinically unstable. Radiographs: loose callus. Deflection 1.120 mm, $s/E_f=1.92$. PTB cast; two crutches. *Fifteen weeks.*—Fracture unstable. Radiographs: increase of callus. Deflection 0.540 mm, $s/E_f=0.73$. *Twenty weeks.*—Weight bearing gradu-

ally increased, occasional full weight bearing for a few steps. Fracture almost stable clinically. Deflection 0.278 mm, s/E_f=0.25. Exercise mobility; first with two crutches, later one, without cast. *Twenty-four weeks.*—Last seven days, full weight bearing. Walks of up to 90 min. Fracture regarded as healed. Deflection 0.186 mm, s/E_f=0.10. *Thirty-eight weeks.*—No residual symtoms. Deflection 0.139 mm, s/E_f=0.02.





CASE 16 Å.D. Typographer, 35 years; fractured tibia in fall. Long leg cast. *Fifteen weeks.*—Clinically unstable. Radiographs: loose callus and clearly visualized fracture gap. Deflection 0.234 mm, s/E_f=0.63. Same day, open reduction and transfixion of fracture with AO screws and long leg cast. *Twenty-seven weeks.*—Fracture clinically stable. Radiographs: good callus. Deflection 0.136 mm, s/E_f=0.18. Cast removed; gradual weight bearing. *Thirty-three weeks.*—Full weight bearing; no residual trouble. Radiographs: consolidation. Deflection 0.119 mm, s/E_f=0.11 Fracture regarded as healed.

CASE 17 R.J. Porter for block of flats, 53 years; fractured skull, ribs and tibia in a road accident. Long leg cast. *Seven weeks.*—Fracture clinically unstable. Radiographs: loose callus. Deflection 0.317 mm, s/E_f=0.49. PTB cast, partial weight bearing. *Twelve weeks.*—Fracture clinically stable. Radiographs: slow increase of callus, minimal on posterior and lateral aspects. Deflection 0.212 mm, s/E_f=0.22. *Sixteen weeks.*—Fracture clinically stable. Radiographs: unchanged callus. Deflection 0.154 mm, s/E_f=0.09. No cast. *Twenty-one weeks.*—Full weight bearing. Radiographs: good callus. Fracture line less distinct. Deflection 0.126 mm, s/E_f=0.02. Union of fracture complete.

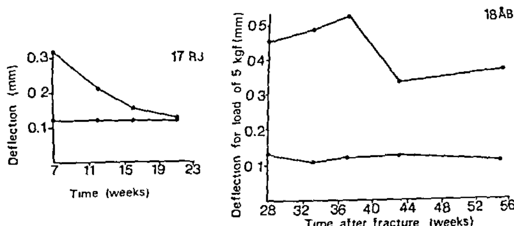




FIGURE 18 *Radiographs of fractured tibia taken 28—55 weeks after fracture* Case 18 A B.

CASE 18 A.B. Dock worker, 42 years; fractured tibia in road accident. Long leg cast. Fracture malunited. Varus position, angle more than 20°. Six months later, walking without support, persistent symptoms owing to foot deformity. Corrective osteotomy attempted; long leg cast worn. *Twenty-eight weeks* after operation.— Osteotomy unstable. Radiographs: poor callus (Fig. 18). Deflection 0.452 mm, s/E_f=0.30. PTB cast; gradual weight bearing. *Thirty-three weeks.*—Clinically unstable. Radiographs: unchanged status. Deflection 0.487 mm, s/E_f=0.35. Continued PTB cast. *Thirty-seven weeks.*—Clinically unstable. Full weight bearing in cast. Deflection 0.522 mm, s/E_f=0.34. PTB cast continued. *Forty-three weeks.*—Some clinical increase in stability—almost stable. Radiographs: fracture line less distinct. Deflection 0.339 mm, s/E_f=0.17. No cast. Full weight bearing. At this fourth measurement reduction in deflection first registered *Fifty-five weeks* —Full weight bearing. Fracture unstable Radiographs: no increase of callus. Deflection 0.370 mm, s/E_f= 0.23. Regarded as a case of delayed healing.

CASE 19 S.K. Office worker, 39 years, amateur footballer. Transverse fracture in the middle of tibia from kick. Long leg cast. Fracture healed well and football training resumed a year later, but a new fracture or refracture occurred. New cast. *Twenty-three weeks* —Attending surgeon doubtful whether to permit full weight bearing. Patient had been walking with crutches for two months without cast. Deflection 0.092 mm, s/E_f=0.03. Radiographs: bridging good callus. Full weight bearing advised; union regarded as complete.

CASE 20 H.M. Saw-mill worker, 21 years, suspected abuse of narcotics; on jumping from third floor window suffered vertebral compression fracture of L_3, acetabular and calcanear fractures and open tibia fracture. This did not heal normally, but valgus position gradually developed, with poor callus. Osteotomy, reduction and immobilization in cast. *Seventeen weeks* —Fracture clinically unstable. Radiographs: poor callus Deflection 0.583 mm, s/E_f=0.40. Walking boot cast. *Twenty-seven weeks* —Clinically stable Full weight bearing, walking without trouble. Unwilling to undergo further examinations.

CASE 21 H.H. Retired head waiter, 63 years; proximal fracture of tibia resulting from fall. Long leg cast. *Fifteen weeks.*—Clinically almost stable. Radiographs: bridging callus, fracture line still visible. Deflection 0.235* mm, s/E_f=0.29; extrapolation from 4 kgf. No cast. Recovery uneventful.

CASE 22 A.C. Shop-keeper, 62 years; proximal fracture of tibia through fall. Long leg cast. *Fourteen weeks.*—Fracture clinically stable. Radiographs: evident callus, but parts of the fracture line clearly visible. Deflection 0.154 mm, $s/E_f=0.18$. No cast; gradual weight bearing. *Nineteen weeks.*—Walking without support. Patient considered fracture as healed and refused further examinations. Fracture regarded as united. Returned to half-time work and 6 weeks later to full time. No residual trouble.

CASE 23 L.H. No regular occupation, 28 years, alcoholic; open fracture of tibia in road accident. Below-knee cast and transfixion with Kirschner wires. Skin necrosis and infection. *Ten weeks.*—Sequestroectomy performed. *Fourteen weeks.*—Fracture clinically unstable. Radiographs: poor callus. Deflection 0.221 mm. Long leg walking boot cast. Patient had no trouble with the leg and himself broke away the cast, returned 10 months later because of recurrence of osteitis in fracture. Walked without difficulty since he had removed the cast. Radiographs: united fracture.

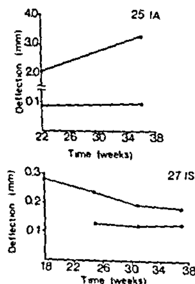
CASE 24 B.Ö. Seaman, 23 years; tibia fractured in accident on board ship. Open reduction and transfixion with an Egger's plate. Returned to work after 6 months. Worked for 3 years, but during military sevice leg pained on strenuous marches. At site of the four-years-old fracture radiographs disclosed thick callus about twice diameter of tibia shaft. Clinically full stability. Deflection 0.088 mm; sound tibia, 0.054 mm. Attending surgeon preferred operation. Healing normal. Returned to work 4 months later. Since fracture was stable before operation, and especially as the metal plate was left in place, there was no reason to perform further measurements of stability.

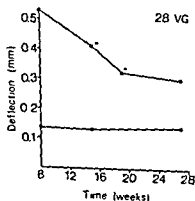
CASE 25 I.A. Shop assistent, 38 years; alcoholic; tibia fractured in road accident. Cast; no healing. *Twenty-two weeks.*—Fracture quite unstable. Deflection 2.03 mm; sound tibia 0.093 mm. Osteosynthesis same day with inlay graft and Hoffman fixation. No union. *Thirty-six weeks.*—Fracture quite unstable. Deflection 3.29 mm; sound tibia, 0.086 mm. A week later re-operation, osteosynthesis with screws and on-lay graft. A month later transferred to the hospital of home-town.

CASE 26 E.J. Electrician, 46 years; oblique fracture of tibia in fall. Reduction and long leg cast. *Twenty-two weeks.*—Fracture clinically unstable according to attending surgeon. Radiographs: evi-

dent callus. Deflection 0.119 mm, $s/E_f I_f = 0.05$. Stability measurements pointed to reliable stability, cast discontinued. Gradual weight bearing permitted. *Twenty-seven weeks.*—Fracture clinically stable; no further measurements; fracture regarded as healed. Returned to full-time work in 3 weeks.

CASE 27 I.S. Cashier, 40 years; fracture of tibia. Plaster cast. *Eighteen weeks.*—Clinically almost stable. At the first attempt to measure stability no sure hold for the distal pins obtained. Radiographs: no evidence of callus. Two days later, with different pin positions, deflection 0.280 mm, $s/E_f = 0.28$. Walking boot cast; gradual weight bearing on cast recommended. *Twenty-five weeks.*—Clinically almost stable. Radiographs: incipient formation of callus. Deflection 0.238 mm, $s/E_f = 0.22$. Walking boot cast. *Thirty-one weeks.*—Fracture clinically stable. Radiographs: incipient callus. Deflection 0.192 mm, $s/E_f = 0.13$. Full weight bearing without support. *Thirty-seven weeks.*—Fracture stable. Radiographs: increase of callus. Deflection 0.181 mm, $s/E_f = 0.09$. Fracture regarded as clinically healed, return to work recommended; five weeks later working full time.





CASE 28 V.G. Clerk, 59 years, fracture of tibia. Long leg cast. *Eight weeks.*—Fracture unstable. Radiographs: incipient callus. Deflection 0.524 mm, $s/E_f = 0.86$. Long leg cast renewed. *Fifteen weeks.*—Fracture almost clinically stable. Deflection 0.410* mm, $s/E_f = 0.58$; extra-

CASE 22 A.C. Shop-keeper, 62 years; proximal fracture of tibia through fall. Long leg cast. *Fourteen weeks.*—Fracture clinically stable. Radiographs: evident callus, but parts of the fracture line clearly visible. Deflection 0.154 mm, s/E_f=0.18. No cast; gradual weight bearing. *Nineteen weeks.*—Walking without support. Patient considered fracture as healed and refused further examinations. Fracture regarded as united. Returned to half-time work and 6 weeks later to full time. No residual trouble.

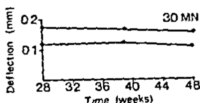
CASE 23 L.H. No regular occupation, 28 years, alcoholic; open fracture of tibia in road accident. Below-knee cast and transfixion with Kirschner wires. Skin necrosis and infection. *Ten weeks.*—Sequestroectomy performed. *Fourteen weeks.*—Fracture clinically unstable. Radiographs: poor callus. Deflection 0.221 mm. Long leg walking boot cast. Patient had no trouble with the leg and himself broke away the cast, returned 10 months later because of recurrence of osteitis in fracture. Walked without difficulty since he had removed the cast. Radiographs: united fracture.

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CASE 25 I.A. Shop assistent, 38 years; alcoholic; tibia fractured in road accident. Cast; no healing. *Twenty-two weeks.*—Fracture quite unstable. Deflection 2.03 mm; sound tibia 0.093 mm. Osteosynthesis same day with inlay graft and Hoffman fixation. No union. *Thirty-six weeks.*—Fracture quite unstable. Deflection 3.29 mm; sound tibia, 0.086 mm. A week later re-operation, osteosynthesis with screws and on-lay graft. A month later transferred to the hospital of home-town.

CASE 26 E.J. Electrician, 46 years; oblique fracture of tibia in fall. Reduction and long leg cast. *Twenty-two weeks*—Fracture clinically unstable according to attending surgeon. Radiographs: evi-

$s/E_f = 0.03$. *Forty-eight weeks.*—Deflection 0.153 mm, $s/E_f = 0.01$. Full weight bearing and walks advised. Three months later patient had loaded the leg fully without trouble and returned to full-time work. Radiographs: consolidation.



CASE 31 K.E. Clerk, 55 years, tibia fractured in road accident. *Thirteen weeks*—Fracture unstable. Radiographs: incipient callus. Deflection 1.290 mm, $s/E_f = 0.54$. Renewed long leg cast. *Twenty-one weeks*—Fracture almost stable. Radiographs: increase of callus (Fig. 19). Deflection 0.760 mm, $s/E_f = 0.29$, two crutches, careful loading. *Twenty-seven weeks*—Clinically stable. Deflection 0.720* mm, $s/E_f = 0.25$, extrapolation from 4 kgf; one crutch. *Thirty-three weeks.*—Deflection 0.540* mm, $s/E_f = 0.17$; extrapolation from 3.5 kgf. Full weight bearing without support. *Forty weeks.*—Walked without trouble. Fracture regarded as clinically healed. Radiographs: fracture consolidated. Deflection 0.389 mm, $s/E_f = 0.11$.

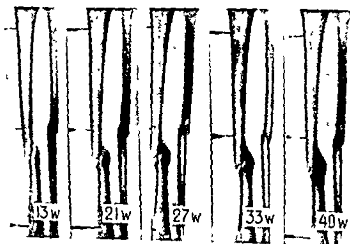
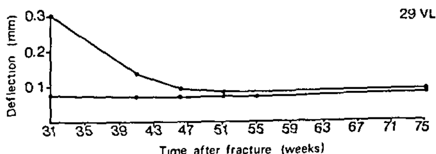


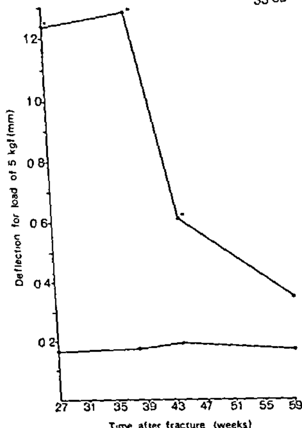
FIGURE 19 *Radiographs of fractured tibia taken 13—40 weeks after fracture* Case 31 K E

polation from 3 kgf. Walking boot cast. *Nineteen weeks.*—Fracture unstable. Radiographs: consolidation of the fracture laterally, incipient consolidation medially. Deflection 0.322 mm, $s/E_f = 0.40$, extrapolation from 3.5 kgf. Cast removed, gradual weight bearing, directed to use two crutches. *Twenty-seven weeks.*—Fracture had then been clinically stable for past month and for two weeks only one crutch had been used. Fracture regarded as healed; no support required. Deflection 0.300 mm, $s/E_f = 0.33$. Nine weeks later half-time work resumed; no residual deformity. Radiographs showed complete consolidation of shaft fracture.

CASE 29 V.L. Housewife, 36 years; transverse fracture of tibia in road accident. Long leg cast. *Thirty-one weeks.*—Clinically almost stable. Radiographs: no over-riding callus; fracture line visible. Deflection (21-cm pin distance) 0.303 mm, $s/E_f = 0.31$. Long walking boot cast. *Thirty-six weeks.*—Fracture clinically stable stability measurement unsuccessful—no radiographs to verify distance from middle pin to centre of fracture. *Forty-one weeks.*—Deflection 0.142 mm, $s/E_f = 0.10$. Cast removed. *Forty-six weeks.*—Fracture stable; full weight bearing. Deflection 0.097 mm, $s/E_f = 0.03$. *Fifty-one weeks.*—Full weight bearing, clinical union. Radiographs: still no over-riding callus on medial aspect of shaft fracture. Deflection 0.088 mm, $s/E_f = 0.02$. Recommended resume work half-time. *Seventy-five weeks.*—Recovery complete, working full-time; no disability. Radiographs: complete consolidation. Deflection 0.099 mm, $s/E_f = 0.02$.

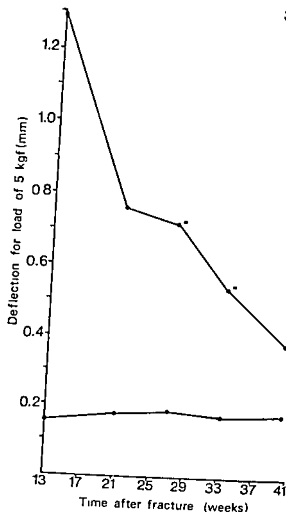


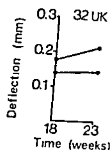
CASE 30 M.N. Housewife, 49 years, open fracture of tibia in road accident. *Twenty-eight weeks.*—Fracture stable for last couple of months. Radiographs: poor callus development. Deflection 0.177 mm, $s/E_f = 0.04$; indicative of good stability; cast removed, weight bearing recommended. *Thirty-nine weeks.*—Because mobility reduced in both knee and ankles, patient had still not dared to put weight on the leg without support. Varus position of ankle; no crutches. Deflection 0.166 mm,



almost stable. Deflection 0.610* mm, s/E_f=0.20, extrapolation from 4 kgf, cast discontinued; two crutches. Sex weeks later fracture clinically stable. *Fifty-nine weeks*.—Deflection 0.349 mm, s/E_f=0.11. Walking without trouble; recovery complete. Radiographs: increasing callus during course of treatment.

CASE 34 K.A. Housekeeper, 50 years, open tibia fracture. Long leg cast. *Fifteen weeks*.—Fracture unstable. Radiographs: no callus. Deflection 1.220 mm, s/E_f=0.86. *Twenty-two weeks*.—Open reduction. Transfixion with AO screw. Long leg cast. *Thirty-nine weeks*.—Fracture unstable. Radiographs: poor callus. Fracture line clearly visible. Deflection 0.745 mm, s/E_f=0.39. *Forty-five weeks*.—Clinically unstable. Deflection 0.560* mm, s/E_f=0.28, extrapolation from 4 kgf. PTB cast; gradual weight bearing. *Fifty-two weeks*.—Clinically stable. Radiographs:





CASE 32 U.K. Dentist, 27 years, tibia fracture during skiing. Long leg cast. *Eighteen weeks.*—Fracture clinically stable. Radiographs: incomplete healing. Deflection 0.154 mm, $s/E_f=0.03$, indicative of stability. Cast discontinued, full weight bearing. *Twenty-three weeks.*—Deflection 0.163 mm, $s/E_f=0.04$. Fracture was regarded as healed.

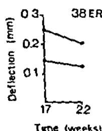
CASE 33 C.S. Clerk, 65 years; tibia fractured in road accident. Long leg cast. *Twenty-seven weeks.*—No union, increasing valgus position. Corrective osteotomy and autologous bone graft. Prior to the operation, deflection 1.240* mm, $s/E_f=0.67$, extrapolation from 4 kgf. *Thirty-eight weeks.*—Eleven weeks after the operation, fracture still unstable. Deflection 1.280* mm, $s/E_f=0.56$, also extrapolated from 4 kgf. Long leg cast; careful loading recommended. *Forty-four weeks.*—Fracture

ration precluded further stability measurement. Radiographs: consolidation of pseudarthrosis.

CASE 36 K.W. Housewife, 44 years, tibia fractured during skiing. Long leg cast. *Twenty-nine weeks.*—Fracture clinically stable. Radiographs: incipient consolidation. Deflection 0.265* mm, s/E_j=0.10. PTB cast 3 more weeks, full weight bearing without support. *Forty-nine weeks.*—Radiographs: consolidation.

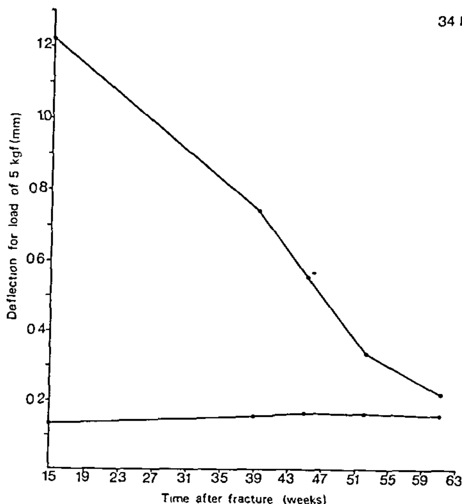
CASE 37 V.N. 75 years; fractured femur (intertrochanteric) and tibia on same side in road accident. Long leg cast. *Thirteen weeks.*—Radiographs: bridging callus, mostly on lateral aspect. Cast discontinued. Deflection 0.360* mm, extrapolation from 3 kgf; sound tibia, 0.200 mm. *Twenty weeks.*—Deflection 0.335 mm. Long walking boot cast because of need to load right leg owing to intertrochanteric fracture. Removed after one week; crutches; gradual weight bearing. Both measurements pointed to good stability. Further course uneventful. *Thirty-six weeks.*—Recovered; full weight bearing.





CASE 38 E.R. Clerk, 18 years, tibia fractured in road accident. Long leg cast. *Seventeen weeks.*—Radiographs: little increase in previously minimal callus. Attending surgeon found stability doubtful. Deflection 0.252 mm, s/E_j=0.15, sound tibia, 0.137 mm; indicative of stability, cast discontinued, two crutches. *Twenty-two weeks.*—Increased weight bearing. Deflection 0.210 mm, s/E_j=0.11. *Twenty-eight weeks.*—Fracture clinically healed, full weight bearing.

CASE 39 A.B. Housewife, 48 years; tibia fractured in road accident. Treated at another hospital; two year later complained of pain on effort. Radiographs: pseudarthrosis; clinically unstable. Deflection 0.553 mm, sound tibia, 0.096 mm. Pseudarthrosis operation, osteosyn-



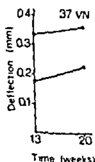
good callus. Deflection 0.340 mm, $s/E_f=0.13$. *Sixty-one weeks.*—Walking without support; clinically healed. Radiographs: increasing callus, fracture consolidated. Deflection 0.227 mm, $s/E_f=0.05$.

CASE 35 A.L. Office cleaner, 60 years; open tibia fracture. Open reduction, osteosynthesis with loops of wire. Long leg cast for three months; fracture regarded as healed. *Fifty-two weeks.*—Complained of pain in leg during walks. Fracture clinically stable. Radiographs: pseudarthrosis with marked sclerotic periosteal reaction. Deflection (21-cm pin distance) 0.108 mm; sound tibia, 0.092 mm; indicative of complete stability. During removal of the wires part of protecting callus chipped away, resulting in mobility between sclerotic bone ends, a pseudarthrosis. Autologous bone graft was inserted. Necrosis of wound margins, secretion, fistula. *Seventy-two weeks.*—Fistula still present. Infection in area of ope-

ration precluded further stability measurement. Radiographs: consolidation of pseudarthrosis.

CASE 36 K.W. Housewife, 44 years, tibia fractured during skiing. Long leg cast. *Twenty-nine weeks.*—Fracture clinically stable. Radiographs: incipient consolidation. Deflection 0.265* mm, s/E_f=0.10. PTB cast 3 more weeks, full weight bearing without support. *Forty-nine weeks.*—Radiographs: consolidation.

CASE 37 V.N. 75 years; fractured femur (intertrochanteric) and tibia on same side in road accident. Long leg cast. *Thirteen weeks.*—Radiographs: bridging callus, mostly on lateral aspect. Cast discontinued. Deflection 0.360* mm, extrapolation from 3 kgf; sound tibia, 0.200 mm. *Twenty weeks.*—Deflection 0.335 mm. Long walking boot cast because of need to load right leg owing to intertrochanteric fracture. Removed after one week; crutches; gradual weight bearing. Both measurements pointed to good stability. Further course uneventful. *Thirty-six weeks*—Recovered; full weight bearing.





CASE 38 E.R. Clerk, 18 years; tibia fractured in road accident. Long leg cast. *Seventeen weeks*—Radiographs: little increase in previously minimal callus. Attending surgeon found stability doubtful. Deflection 0.252 mm, s/E_f=0.15, sound tibia, 0.137 mm, indicative of stability, cast discontinued; two crutches. *Twenty-two weeks*—Increased weight bearing. Deflection 0.210 mm, s/E_f=0.11. *Twenty-eight weeks.*—Fracture clinically healed; full weight bearing.

CASE 39 A.B. Housewife, 48 years; tibia fractured in road accident. Treated at another hospital; two year later complained of pain on effort. Radiographs: pseudarthrosis; clinically unstable. Deflection 0.553 mm, sound tibia, 0.096 mm. Pseudarthrosis operation, osteosyn-

thesis with screws and autologous bone graft. Postoperative course uneventful; normal recovery time.

CASE 40 B.H. Nurse, 50 years; tibia fractured in road accident. Reduction, long leg cast. *Thirteen weeks.*—Radiographs: minimal callus. *Sixteen weeks.*—Clinically unstable. Deflection 0.400* mm, $s/E_f I_f = 0.55$; sound tibia, 0.155 mm. Walking boot cast. Returned to former hospital for further treatment. Recovery uneventful.

CASE 41 M.Z. Clerk, 67 years; trimalleolar fracture. Patient not included in series but values included in analysis of error of determination of deflection of sound tibia and moment of inertia from formula for I_{appr} because two measurements had been performed on sound tibia and radiographs had been taken in suitable projections. Determinations performed 4 and 6 months after fracture.

Results

The values of s/E_f or $s/E_f I_f$ obtained at the examinations where the clinical evaluation of the stability of the fracture was followed by a new step in treatment or where the fracture was regarded as stable are given in the table 13. Treatment with walking boot cast was given in the interval $s/E_f = 0.66—0.21$ ($n = 17$); removal of the cast and use of two crutches was begun at the value of 0.31 ($n = 12$); the fracture was judged to be stable when $s/E_f = 0.30—0.17$ ($n = 22$) and full weight bearing was introduced at $s/E_f = 0.17—0.10$ ($n = 17$).

The healing time for the fracture varied individually and the average time after fracture until full weight bearing was resumed was 33 weeks (range 16—69) for 34 patients.

The stability of the callus is expressed by the ratio s/E_f, whose values at various intervals after fracture have been entered in figure 20. The slope of the line between two measurements gives the average rate of healing. The advantage of expressing the deflection of the callus by the ratio s/E_f instead of δ_f is that the former relates to a specific deflection per unit of inverse moment of inertia and per unit load for any particular case; the measurement δ_f is dependent on the factors governing the magnitude of the deflection—for example, the distance between the nearer outer pin and the fracture, the moment of inertia and the load.

In cases 8 and 9 the ratio $s/E_f I_f$ is plotted in figure 20. To judge from their physical constitution the value of I_f should lie on the positive side close to the mean of I_{appr} for the male cases (0.94 cm^4). This would give a value about 1.0 cm^4 for I_f.

ABLE 12 *Recorded deflection of the fractured (v_{tot}) and sound tibia (v_t) during the course of healing, and the corresponding values of s/E_f (Italic numbers are extrapolated values)*

Case	Weeks	v_{tot} (mm)	v_t (mm)	s/E_f ($s/E_f l_f$)
1 L.H.	22	.172	.092	.44
	28	.138	.098	.23
	34	.128	.095	.18
2 H.W.	8	.282	.107	.36
	13	.217	.109	.19
	17	.190	.104	.15
3 S S	17	.249	.080	.27
	21	193	.080	.18
	27	.118	086	.06
	31	.098	.087	02
	39	.095	086	.02
4 L B	39	.308	076	.29
	48	.192	071	14
	55	.140	076	08
	64	.119	076	06
	74	.106	082	.04
	86	116	.082	05
5 K.F.	6	882	083	2.04
	11	.450	076	.94
	16	278	.080	50
	20	170	071	22
	26	148	.080	17
	41	129	087	13
6 L.L.	38	209	.104	.21
	44	.150	.083	08
	50	.147	.093	08
	63	.143	.114	07
7 F.S	22	680	093	.79
	31	.150	.078	.08
	49	104	.093	.02
8 N.S	17	.246	124	(.13)
	22	.180	.132	(.06)
	30	.130	.110	(01)
	40	.099	.109	(<0)
9 G W	18	.560	.118	(1.10)
	22	.305	.120	(.53)
	27	.212	.106	(24)
	30	.160	—	(.12)
	39	.125	.106	(03)
10 G.S	6	.510	.081	1 13
	10	.290	086	.85
	16	.120	.088	.18
	20	.113	.084	.15
	29	106	.090	11
11 G C.	32	.500	084	.36
	41	.430	.091	.29
	57	.218	100	.13
	70	.162	096	06
12 L.P	34	.880	.093	1 75
	41	530	.098	.96
	47	.392	.092	.67
	53	493	.095	.88
	60	250	086	.35
	69	.226	.097	.30
	84	127	.090	.07
13 E.S.	14	1.210	.096	1.55
	21	1.200	091	1.57
	25	.718	.090	.90
	34	446	.096	49
	38	.376	087	.41
	45	222	.079	.19
	52	.149	.089	.08
14 S G	15	.243	088	.41
	21	.222	095	.26
	27	110	086	06
	32	.100	094	.02
15 N G	8	1.120	117	1 92
	15	.540	.130	.73
	20	.278	.131	.25
	24	.186	.131	10
	38	.139	.122	02

thesis with screws and autologous bone graft. Postoperative course uneventful; normal recovery time.

CASE 40 B.H. Nurse, 50 years; tibia fractured in road accident. Reduction, long leg cast. *Thirteen weeks.*—Radiographs: minimal callus. *Sixteen weeks.*—Clinically unstable. Deflection 0.400" mm, $s/E_f I_f = 0.55$; sound tibia, 0.155 mm. Walking boot cast. Returned to former hospital for further treatment. Recovery uneventful.

CASE 41 M.Z. Clerk, 67 years; trimalleolar fracture. Patient not included in series but values included in analysis of error of determination of deflection of sound tibia and moment of inertia from formula for I_{appr} because two measurements had been performed on sound tibia and radiographs had been taken in suitable projections. Determinations performed 4 and 6 months after fracture.

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The values of s/E_f or $s/E_f I_f$ obtained at the examinations where the clinical evaluation of the stability of the fracture was followed by a new step in treatment or where the fracture was regarded as stable are given in the table 13. Treatment with walking boot cast was given in the interval $s/E_f = 0.66$—0.21 ($n = 17$); removal of the cast and use of two crutches was begun at the value of 0.31 ($n = 12$); the fracture was judged to be stable when $s/E_f = 0.30$—0.17 ($n = 22$) and full weight bearing was introduced at $s/E_f = 0.17$—0.10 ($n = 17$).

The healing time for the fracture varied individually and the average time after fracture until full weight bearing was resumed was 33 weeks (range 16—69) for 34 patients.

The stability of the callus is expressed by the ratio s/E_f, whose values at various intervals after fracture have been entered in figure 20. The slope *of the line between two measurements gives the average rate of healing.* The advantage of expressing the deflection of the callus by the ratio s/E_f instead of δ_f is that the former relates to a specific deflection per unit of inverse moment of inertia and per unit load for any particular case; the measurement δ_f is dependent on the factors governing the magnitude of the deflection—for example, the distance between the nearer outer pin and the fracture, the moment of inertia and the load.

In cases 8 and 9 the ratio $s/E_f I_f$ is plotted in figure 20. To judge from their physical constitution the value of I_f should lie on the positive side close to the mean of I_{appr} for the male cases (0.94 cm^4). This would give a value about 1.0 cm^4 for I_f.

TABLE 12 *Recorded deflection of the fractured (v_{tot}) and sound tibia (v_t) during the course of healing, and the corresponding values of s/E_f (Italic numbers are extrapolated values)*

Case	Weeks	v_{tot} (mm)	v_t (mm)	s/E_f (s/E_fI_f)
1 L.H	22	.172	.092	.44
	28	.138	.098	.23
	34	.128	.095	.18
2 H.W.	8	.282	.107	.36
	13	217	.109	19
	17	190	.104	.15
3 S.S	17	.249	.080	.27
	21	193	.080	.18
	27	.118	.086	06
	31	098	.087	.02
	39	.095	086	02
4 L.B.	39	.303	076	.29
	48	.192	071	14
	55	140	076	08
	64	.119	.076	.06
	74	.106	082	.04
	86	.116	082	05
5 K.F.	6	882	083	2.04
	11	.450	076	94
	16	.278	.080	.50
	20	170	071	.22
	26	.148	.080	.17
	41	.129	087	.13
6 L.L.	38	.209	104	.21
	44	.150	083	.08
	50	.147	.093	08
	63	143	.114	07
7 F.S	22	680	.093	.79
	31	.150	.078	08
	49	.104	.093	.02
8 N.S	17	.246	124	(.13)
	22	.180	.132	(06)
	30	.130	.110	(.01)
	40	.099	.109	(<0)
9 G.W	18	.560	.118	(1.10)
	22	.305	.120	(.53)
	27	.212	106	(.24)
	30	.160	—	(.12)
	39	125	.106	(.03)
10 G.S	6	.510	081	1.13
	10	.290	.086	85
	16	120	088	18
	20	113	.084	.15
	29	106	.090	.11
11 G.C	32	.500	.084	.36
	41	430	091	.29
	57	.218	100	.13
	70	162	096	06
12 L.P	34	880	093	1 75
	41	530	.098	96
	47	*392*	*.092*	*.67*
	53	493	.095	88
	60	250	086	.35
	69	.226	097	30
	84	127	090	07
13 E.S	14	1.210	096	1.55
	21	1.200	091	1.57
	25	718	090	90
	34	446	.096	.49
	38	.376	087	41
	45	.222	079	39
	52	.149	.089	08
14 S.G	15	.243	088	41
	21	.222	095	.26
	27	110	086	06
	32	100	.094	02
15 N.G	8	1.120	.117	1.92
	15	.540	.130	.73
	20	.278	.131	.25
	24	.186	131	10
	38	.139	.122	02

thesis with screws and autologous bone graft. Postoperative course uneventful; normal recovery time.

CASE 40 B.H. Nurse, 50 years; tibia fractured in road accident. Reduction, long leg cast. *Thirteen weeks.*—Radiographs: minimal callus. *Sixteen weeks.*—Clinically unstable. Deflection 0.400* mm, $s/E_fI_f=0.55$; sound tibia, 0.155 mm. Walking boot cast. Returned to former hospital for further treatment. Recovery uneventful.

CASE 41 M.Z. Clerk, 67 years; trimalleolar fracture. Patient not included in series but values included in analysis of error of determination of deflection of sound tibia and moment of inertia from formula for I_{appr} because two measurements had been performed on sound tibia and radiographs had been taken in suitable projections. Determinations performed 4 and 6 months after fracture.

Results

The values of s/E_f or s/E_fI_f obtained at the examinations where the clinical evaluation of the stability of the fracture was followed by a new step in treatment or where the fracture was regarded as stable are given in the table 13. Treatment with walking boot cast was given in the interval $s/E_f=0.66$—0.21 ($n=17$); removal of the cast and use of two crutches was begun at the value of 0.31 ($n=12$); the fracture was judged to be stable when $s/E_f=0.30$—0.17 ($n=22$) and full weight bearing was introduced at $s/E_f=0.17$—0.10 ($n=17$).

The healing time for the fracture varied individually and the average time after fracture until full weight bearing was resumed was 33 weeks (range 16—69) for 34 patients.

The stability of the callus is expressed by the ratio s/E_f, whose values at various intervals after fracture have been entered in figure 20. The slope of the line between two measurements gives the average rate of healing. The advantage of expressing the deflection of the callus by the ratio s/E_f instead of δ_f is that the former relates to a specific deflection per unit of inverse moment of inertia and per unit load for any particular case; the measurement δ_f is dependent on the factors governing the magnitude of the deflection—for example, the distance between the nearer outer pin and the fracture, the moment of inertia and the load.

In cases 8 and 9 the ratio s/E_fI_f is plotted in figure 20. To judge from their physical constitution the value of I_f should lie on the positive side close to the mean of I_{appr} for the male cases (0.94 cm^4). This would give a value about 1.0 cm^4 for I_f.

TABLE 13 *Values s/E_f and (s/$E_f I_f$) at various stages of treatment. The ranges are those between which treatment was changed, or the fracture was clinically stable. (Italic numbers are extrapolated values.)*

Case	Walking boot cast	Without cast		Fracture clinically stable	Full weight bearing
		Two crutches	One crutch		
1	—.44		.44—.23	—.23	.23—.18
2	.36—.15			.36—.19	.15—06
3	.27—06			27—.18	.18—.06
4	.29—.08			.29—.14	.08—.06
5	.94—.50	.50—	.22—	50—.22	.22—.17
6		.21—		.21—08	.21—.08
7	.79—			—.08	—.08
8	(13—)			(—13)	(06—)
9		(53—)	(24—)	(—.53)	(—.12)
10	.85—	.15—		—.18	15—.11
11		36—	.29—	.29—.13	.23—.13
12	1.75—.30		30—		—.07
13	90—19		.19—	.41—.19	.19—08
14	41—.06		06—	.26—06	.26—06
15	1 92—25		.25—	25	.25—.10
16	—18			—.18	.18—.11
17	49—09	09—		.22—09	.09—
18	—35				.23—.17
20	40—				
21		61—			
22				—.41	.41—
27	28—13	13—		.22—.13	.13—.09
28	*58*—40	40—	.33—	.40—.33	
29	30—10		.10—	—.03	.03—
31		29—	*.25*—	.29—.25	*.17*—.11
33	*56*—.20	20—		.20—.11	.11—
34	*.28*—13		.13—	—.13	13—.05
36				—*.10*	
38		(15—)			
40	(*55*—)				

TABLE 12, *continued.*

Case	Weeks	v_{tot} (mm)	v_t (mm)	s/E_f (s/E_fI_f)
16 Å.D.	15	.234	.094	.63
	27	.136	.093	.18
	33	.119	.086	.11
17 R.J.	7	.317	.122	.49
	12	.212	.121	.22
	16	.154	.117	.09
	21	.126	.117	.02
18 Å.B.	28	.452	—	.30
	33	.487	.107	.35
	37	.522	.117	.34
	43	.339	.124	.17
	55	.370	.111	.23
19 S.K.	23	.092	.068	.03
20 H.M.	17	.583	.145	.40
21 H.H.	15	*.235*	.137	*.29*
22 A.C.	14	.154	.105	.18
23 L.H.	14	.221	.085	
24 B.Ö.	—	.088	.054	
25 I.A.	22	2.030	.093	
	36	3.290	.086	
26 E.J.	22	.119	.090	(.05)
27 I.S.	18	.280	—	.28
	25	.238	.130	.22
	31	.192	.125	.13
	37	.181	.130	.09
28 V.G.	8	.524	.135	.86
	15	*.410*	.132	*58*
	19	*.322*	—	*40*
	27	.300	.141	.33
29 V.L.	31	.303	.077	.31
	41	.142	.074	.10
	46	.097	.073	.03
	51	.088	.075	.02
	55	—	.077	—
	75	.099	.088	.02
30 M.N.	28	.177	.123	.04
	39	.166	.124	.03
	48	.153	.117	.01
31 K.E.	13	1.290	.158	.54
	21	.760	.179	.29
	27	*.720*	.189	*.25*
	33	*.540*	.176	*.17*
	40	.389	.183	.11
32 U.K.	18	.154	.139	.03
	23	.163	.143	.04
33 C.S.	*27*	*1.240*	*.167*	*.67*
	38	*1.280*	.175	*.56*
	44	*.610*	.194	*.20*
	59	.349	.168	.11
34 K.Å.	15	1.220	—	.86
	39	.745	.159	.39
	45	*.560*	.168	*.28*
	52	.340	.165	.13
	61	*.227*	.162	.05
35 A.L.	—	.108	.092	.04
36 K.W.	29	*.265*	.124	*.10*
37 V.N	13	*.360*	.175	
	20	*335*	225	
38 E R	17	252	143	(15)
	22	.210	.130	(11)
39 A.B.	—	.553	096	
40 B H.	16	*400*	.155	(*55*)

TABLE 13 *Values s/E_f and (s/E_fI_f) at various stages of treatment. The ranges are those between which treatment was changed, or the fracture was clinically stable. (Italic numbers are extrapolated values.)*

Case	Walking boot cast	Without cast		Fracture clinically stable	Full weight bearing
		Two crutches	One crutch		
1	—.44		.44—23	—23	.23—.18
2	.36—.15			.36—.19	.15—06
3	.27—.06			.27—.18	.18—06
4	.29—.08			29—.14	.08—.06
5	.94—.50	.50—	.22—	.50—.22	.22—.17
6		.21—		.21—08	.21—.08
7	.79—			—.08	—.08
8	(.13—)			(—13)	(06—)
9		(53—)	(.24—)	(—.53)	(—.12)
10	85—	.15—		—18	15—11
11		36—	.29—	.29—.13	.23—.13
12	1.75—.30		.30—		—.07
13	90—.19		.19—	.41—.19	.19—08
14	41—06		.06—	.26—06	.26—06
15	1 92—25		25—	.25	.25—10
16	—18			—.18	18—.11
17	49—09	09—		.22—.09	.09—
18	—35				23—17
20	40—				
21		61—			
22				—.41	.41—
27	28—13	.13—		.22—.13	.13—09
28	58—40	40—	.33—	.40—33	
29	30—10		10—	—03	.03—
31		29—	.25—	.29—25	17—.11
33	56—20	20—		20—.11	.11—
34	.28—13		.13—	—13	.13—.05
36					
38					
40	(55—)	(15—)		—.10	

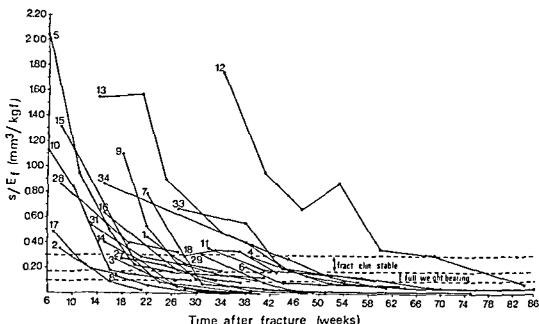


FIGURE 20 *Upper.—The ratio s/E_f as a function of time*
Lower.—The inverse ratio (E_f/s) as a function of time

The slope of the curves for the various cases indicates the rate of healing, expressed as a decrease in specific deflection and as an increase in stiffness of the callus, respectively.

The rate of healing can also be expressed in terms of the increase in the stiffness of the callus with time. When the deflection within the callus tends to zero—that is to say, when the deflection of the fragments accounts for nearly the whole of the total deflection of the tibia—E_f tends to high values. Curves of E_f/s as a function of time are shown in figure 20.

The limits within which full weight bearing was started or clinical stability of the fracture was first noted are given in the two figures.

In four cases, 4, 32, 33 and 37, a slight increase in deflection was found to have occurred between two examinations (Table 12). In three of these cases the measurements in question were performed after full weight bearing had begun, and at most a small reduction in deflection would be expected; however, the values do not differ by more than can be ascribed to the error of the method. In the fourth case, no. 33, the explanation may be the same, although here it is at the second measurement that the increase was recorded. It could than have its explanation in extremely slow healing in the interval; but, again it might also be due to the random error of the method.

At three examinations an increase of more than 10 per cent was recorded. In case 12 the deflection was 25 per cent greater after 53 weeks than after 47; this increase must probably be ascribed to a reduction in the stability of the fracture. The long period of immobilization had resulted in stiffness of the knee and ankle and the cast was therefore removed and physiotherapy given. When, after the fifty-third week, a knee cast had been furnished and weight could be put on leg, the stability increased.

In case 18 the corrective osteotomy was followed by delayed union. The second, third and fifth values showed increases in deflection of 8, 7 and 9 per cent, whereas the fourth value indicated a reduction of 35 per cent. Here, too, the figures probably represent the true state of affairs; for during the first three measurements and between the fourth and the fifth there was no signs of progress in healing and it is probable that a pseudarthrosis was in the course of formation. For some reason—perhaps an increase in the load on the transverse fracture while the PTB cast was being worn —signs of stabilization were noted between the third and the fourth measurements. No further measurements of the deflection have yet been made.

In case 25 the deflection measurements were followed immediately by operations to hasten healing in the extremely mobile fracture, with a consequent change in the experimental conditions between the two measurements.

VII. Discussion

ACCURACY OF THE METHOD

The observed deflection of the bone contains an error that is dependent on the reliability of the measuring instrument. A further error is that inherent in the principle of the method, which is strictly applicable to a simple beam, whereas here we are concerned with a body of irregular shape and structure, composed, moreover, of biological tissue.

The total measurement error of the registration unit was ±1.2 per cent. There is a systematic error of the method by virtue of the bending of the instrument and the local resilience of the bone around the pins; this error was calculated at 39 and 29 μm at pin distances of 24 and 21 cm, respectively. To obtain an impression of this local resilience measurements were made of the displacement in various materials, namely, pieces of spruce wood, ebonite, oak and laminated bakelite. The respective displacements were 36, 27, 21 and 10 μm. It may be inferred that the resilience of the pins is dependent to some extent on the physical properties of the various bones. This means that the application of a constant correction will increase the deviation of the values obtained in the calculation of the modulus of elasticity.

It is difficult to obtain a secure hold for the pin tips in bone with a thin cortex. Two attempts were made to replace the ordinary pins that had perforated the cortex with ones having threaded tips, which would be expected to give a better hold in the cortex. The values then obtained were the same as those values extrapolated from the curve.

The variation in the shape of the tibia and its heterogenous structure affect the determinations of both deflection and moment of inertia. From a visual estimate of the direction of the principal central axes of the moment of inertia of the section at different levels on 10 specimens and from an integrator determination in one specimen (Fig. 3) it would appear that these axes are practically parallel. It is only in the condylar area and near the malleolus that the principal central axes change direction; here the cross section is closer to a circle and, since the difference between the

maximum and the minimum moments of inertia of the section is small, the directions of the axes are of relatively little importance. The anterior crest has a sigmoid course and, as can be seen in figure 3, it twice intersects the plane of the principal axes. On section +12 the tuberosity of the tibia lies *on the medial side of the principal central axes* and on section +6 the crista anterior just passes across to the lateral side and then, in section —6, returns to the medial side. Thus, the torsion due to any twisting of the tibia's bending plane for the minimum moment of inertia may be neglected. On the other hand, the angle between the bending plane of the instrument and that for the minimum moment of inertia of the tibia when the longitudinal axes are parallel can decrease the observed deflection by up to 3 per cent. When the bending planes intersect and when they are translated and the longitudinal axes of the instrument and the tibia are kept mutually parallel, the deflection due to pure bending is increased by a torsional component; this amounts to about 2 per cent of the observed deflection.

Of greater importance, however, is the position of the middle pin. This should be the same for different measurements on the same bone, but this ideal is not always achieved. One of the reasons why a change in level of the middle pin has taken place is the difficulty of determining the contour of the medial malleolus, especially when the ankle is swollen. An attempt was made to retain the marking from one occasion to the next in order more easily to identify the sites for the pins. The most effective procedure was to fill in the old marks after the cast had been removed and before the bone was sterilized.

The deflection of the fractured tibia would presumably be affected by stress in the surrounding tissues, by any swelling of the leg and by the fluid content of the bone tissue (Sedlin & Hirsch, 1966). Opinions differ on whether the bone might be hydraulically strengthened, through the effect of the blood pressure or muscle contraction (McPherson & Juhasz, 1965; Swanson & Freeman, 1966). As, however, the significance of these factors is small and probably essentially the same for the different tibias it may be disregarded in the evaluation of the stability of the fracture.

The determination of the moment of inertia from eqn. [8] incurred a small measurement error, and the reproducibility was satisfactory. If the variation of the moment of *inertia along the tibia* is taken into account an even more reliable expression for the modulus of elasticity for a single observation is obtained. This was done by calculating the moments of inertia from other approximation formulae as eqn. [8] at different levels of the tibia, thereby obtaining an individual and more correct constant in eqn. [9].

The ratio s/E_f is estimated on the basis of several assumptions and approximations. The line of fracture varies and the length of the callus, the modulus of elasticity and the moment of inertia of the callus are none of them properly defined measures; s and E_f are used solely as an aid in determining the additional deflection caused by the callus of the fractured bone, and insofar as the callus cannot be regarded as a short beam or spring joint, these two terms cannot be considered to represent the real length of the callus or its modulus of elasticity.

In the mathematical model the viscous element, its variation with time, and the shear in the callus are disregarded. Nor is it entirely correct to assume that the recorded deflection of the bone fragments are identical with that of the sound tibia v_t having the same systematic error of measurement for the fractured and the sound tibia (see eqn. [12]).

Because of metabolic and circulatory changes, however, this would result in a smaller value of δ_f. Experiments on laboratory animals have shown that the healing of fractured bone is accompanied by changes in the physical properties of bone substance. The resistance of the tibia condyle to compression has been found to be lower for the bone with the fractured shaft (Nilsson & Smith, 1969).

Any variation in the ratio s/E_f is due chiefly to a change in the value of E_f. According to Henry *et al.* (1968) there is a linear relationship between the stiffness and the breaking strength of the damaged leg. In bending experiments on the rabbit in which one radius had been fractured surgically, these authors showed that during the course of healing the ratio between the ultimate breaking strengths of the fractured and sound radii varied directly as the ratio between the stiffnesses of the fractured and sound radii. The slope of the line was 0.48; that is to say, when the stiffness ratio was unity the strength ratio was about 0.5.

This would mean that when the recorded deflections of the fractured and the intact tibia are equal, the ultimate bending strength of the callus is half of the intact tibia at the same level. In the experiments on rat tibia, Wray & Goodman (1963) found that the breaking strength 65 days after the surgically produced fracture was greater for the fractured than the sound tibia, and after the 80th day the difference was statistically significant.

From the curves of s/E_f as a function of time in figure 20 (upper) it is seen that the specific deflection of the callus during the course of healing decreased at a varying rate. The curves of E_f/s as a function of time show that the increase in stiffness of the callus also occurs at a varying rate (Fig. 20, lower part). According to the study by Henry *et al.*, when there is no

deflection of callus, that is, when $\delta_f = 0$, its ultimate breaking strength is one half that of the sound tibia bone at the same level. This would mean that up to the breaking point the callus becomes more resistent to bending forces; but there is no deflection of the fractured tibia through any weakening at the fracture site. Thus, during the further healing of the fracture the ultimate breaking strength will increase while the flexural rigidity remains constant. Clinicians consider that in general a fracture is healed, when the stiffness has been recovered. However, as the mineralization of the callus is then still incomplete it would appear that the strength goes on increasing until osseous consolidation is complete and the bone structure fully restored.

CLINICAL VALUE OF THE METHOD

In cases where union is delayed or pseudarthrosis is suspected it is necessary to examine whether healing can be expected at all. Just what is to be gained from an operation to hasten the process is not always obvious. Most workers assess the indications for surgery on the basis of the time that has elapsed since the fracture occurred, but a long interval does not necessarily mean that the development of the stability of the fracture has stopped and it is this that should decide whether an operation should be performed. Without an objective knowledge of the stability of the fracture, it is impossible to decide whether an operation is indicated. The method reported not only provides the means for resolving this dilemma; it also enables an objective evaluation of different forms of treatment to be made.

An experienced investigator requires about 30 minutes to perform a determination of the deflection on both legs, with the accompanying radiographic examination. To appraise the development of the stability in a single case, however, it is enough to measure the deflection of the fractured bone under the same conditions two or three times over a convenient period, and each measurement will require only 10 minutes or so. In over 900 pin insertions there were no signs of infection or subsequent irritation, or of any other complications. The examinations were performed under local anaesthetic and are painless.

The bending test technique can be applied to other shaft fractures, such as those of the femur, but then another, longer, measuring beam has been used. It may also be possible to use the method for diagnostic purposes in diseases affecting bone.

CONCLUSIONS

The bending of the tibia *intra vitam* under a force of 5 kgf can be determined in a single measurement to an accuracy of 5 per cent for men and 8 per cent for women.

The minimum moment of inertia of the tibia can be found in a single measurement to an accuracy of 5 per cent.

An *intra vitam* determination of the modulus of elasticity of the tibia can be made in a single measurement to an accuracy of 10 per cent, while for young males in sound health the error incurred in the measurement of the modulus of elasticity was 5 per cent.

The values obtained for the modulus of elasticity are probably on the high side because it was impossible to determine the moment of inertia in spongy bone.

The method is intended primarily for patients with fractures of the tibia shaft. Of the 133 measurements performed on fractured tibias there were only 3 where a straightforward interpretation of the value could not be made.

VIII. Summary

The object of this investigation was to devise a method for obtaining an objective measure of the stability of a fracture of the tibia shaft during the course of healing.

An instrument has been designed with which the deflection of the bone can be registered as a function of the applied force.

The deflection of a bone is dependent on the moment of inertia of the section and the modulus of elasticity. A procedure has been evolved for determining the moment of inertia from a radiograph. It is thus possible to compare the deflection of various bones in terms of the varying modulus of elasticity in bending.

The accuracy of the method was examined on 20 pairs of autopsy specimens in 40 patients with tibial shaft fractures and in 9 voluntary subjects.

During the course of healing the gap between the fragments is filled with callus, whose physical properties gradually change towards those of bone. This implies a decrease in the deflection due to the weakness of the callus. As healing progresses the stiffness of the callus increases. On the basis of the values obtained from measurements carried out with the described method an expression has been deduced by means of which it is possible to compare the degree of healing in terms of quantities that are equivalent to the stiffness of fracture callus.

The clinical series consisted of 26 men and 14 women with a fracture of the tibia shaft; in most of them union was slow. The first stability measurement with the method was made, on average, 19 weeks after the fracture, and determinations were continued until full loading of the fractured leg was possible—on average 33 weeks after the fracture.

Altogether 133 such determinations were performed on fractured tibias; in only three could no definitive conclusions be drawn as regards the development of stability.

The clinical application of the method for examination of the fracture was instructive and facilitated the evaluation of the course of healing. The measurements were performed ambulatory under local anaesthetic. In more

than 900 cases there was no infection or other complication. The examination took on average 30 minutes.

In the case of delayed union the appraisal of the stability of the fracture by means of the method can be of value in deciding whether to resort to an operation in order to hasten union.

IX. *Acknowledgements*

The design of the method of measurement, the construction of the measuring instrument, and the solution of the problems associated with the electronic registration and the experimental part of the investigation were performed at the Department of Medical Engineering, Karolinska Institute; the clinical part of the study was carried out at the Department of Orthopaedic Surgery, Karolinska Institute, Stockholm.

The theoretical analysis of the mechanics of the tibia was performed in collaboration with Christer Swerup, Civ. ing. Department of Physics, The Royal Institute of Technology, Stockholm.

The statistical analysis was performed under the guidance of Bo Lindström, M.D., the Department of Medical Physics, Karolinska Institute, Stockholm.

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X. References

ANDREWS, E. S.: The Theory and Design of Structures. Chapman & Hall, London 1934.

BAUMEISTER, T., MARKS, L. S.: Standard Handbook for Mechanical Engineers. Mc Graw-Hill, New York, London. 7th Ed, 1958.

BELL, G. H., CUTHBERTSON, D. P., ORR, J.: Strength and size of bone in relation to calcium intake. J. Physiology: *100*, 299—317, 1941.

BLAIMONT, P.: Contribution à l'étude biomécanique du fémur humain. Acta Orthop. Belg.: *34*, 665—844, 1968.

BLAIMONT, P., BURNY, F.: Resistance à la traction et dureté de la diaphyse femorale Acta Orthop. Belg.: *34*, 883—892, 1968.

CAROTHERS, C. O., SMITH, F. C., CALABRIS, P.: The elasticity and strength of some long bones of the human body. Naval Med. Res. Inst. Project NM 001 056.02.13, 1949.

COMTET, J. J., ROZIER, T., VASSAL, R., ARENE, J. M., FIRSCHER, L.: Recherches expérimentales sur la résistance de la diaphyse, des os longs chex l'homme. Rev. Chir. Orthop.: *53*, 3—21, 1967.

CURREY, J. D.: Difference in tensile strength of bone of different histological types. J. of Anat.: *93*, 87—95, 1959.

CURREY, J. D.: Three analogies to explain the mechanical properties of bone. Biorheology: *2*, 1—10, 1964.

CURREY, J. D.: The mechanical consequences of variation in the mineral content of bone. J. Biomechanics: *2*, 1—11, 1969.

DEMPSTER, W. T., LIDDICOAT, R. T.: Compact bone as a non-isotopic material. Am. J Anat.: *91*, 331—362, 1952.

DEMPSTER, W. T., COLEMAN: Tensile strength of bone along and across the grain structure composition J. Appl. Physiol.: *16*, 355, 1961.

EVANS, F. G.: Stress and Strain in Bones. Charles C Thomas, Springfield, Illinois, 1957.

EVANS, F. G.: Relations between the microscopic structure and tensile strength of human bone. Acta Anat : *35*, 285—301, 1958

EVANS, F. G.: Studies on the Anatomy and Function of Bone and Joints Springer-Verlag, Berlin, Heidelberg, New York, 1966

GLIMCHER, M J : Molecular biology of mineralized tissues with particular reference to bone. Rev. Mod Phys : April, 1959.

GRUNEWALD, J · Die Beanspruckning der langen Rohrenknochen des Menschen Ztschr f. Orthop Chir : *39*, 27—49, 129—147, 257—286, 1920

HENRY, A. N., FREEMAN, M. A. R , SWANSON, S A V · Studies on the mechanical properties of healing experimental fractures Proc Roy Soc. Med · *61*, 40—44, 1968.

HIRSCH, C , EVANS, G F · Studies on some physical properties of infant compact bone. Acta Orthop Scand : *35*, 300—313, 1965

HIRSCH, C., da SILVA, O.: The effect of orientation on some mechanical properties of femoral cortical specimens. Acta Orthop. Scand.: *38*, 45—56, 1967.

KNESE, K. H, HAHNE, O. H, BIERMANN, H.: Festigkeituntersuchungen an menschlichen Extremitätenknochen. Gegenbauers Morph. Jahrbuch: *96*, 141—229, 1956.

KNESE, K. H: Knochenstruktur als Verbundbau. Thieme, Stuttgart, 1958.

KOCH, J. C.: The laws of bone architecture. Am. J. Anat.: *21*, 177—298, 1917.

LANG, S. B: Elastic coefficients of animal bone. Science: *165*, 287—288, 1969.

LINDAHL, O, LINDGREN, A. G. H.: Cortical bone in man. Acta Orthop. Scand: *38*, 133—147, 1967, *39*, 129—135, 1968.

MACK, R. W.: Bone—a Natural Two-phase Material. A technical memorandum of Biomechanics Laboratory, Univers. of Calif., San Francisco, Berkeley, Oct., 1964.

MARIQUE, P.: Etudes sur *le fémur*. Librairie des Sciences. Bruxelles, 1945

MATHER, B. S.: Correlations between strength and other properties of human long bones. J Trauma: *7*, 633—638, 1967.

MATHER, B. S.: A method of studying the mechanical properties of human long bones. J Surg Res., *7*, 222—225, 1967.

MATHER, B. S: Variation with age and sex in strength of the femur. Med. Elec. Biol. Engng. 6, 129—132, 1968

MATHER, B S: The effect of variation in specific gravity and ash content on the mechanical properties of human compact bone. J. Biomechanics: *1*, 207—210, 1968.

McELHANEY, J., FOGLE, J., BYARS, E., WEAVER, G.: Effect of embalming on the mechanical properties of beef bone. J Appl. Physiol: *19*, 1234—1236, 1964.

McPHERSON, A., JUHASZ, L.: The haemodynamics of bone. *In* Biomechanics and Related Bio-Engineering Topics Pergamon Press. London. Ed. R. M. Kenedi p. 181, 1965,

MOLNAR, Z.: Additional observations on bone crystal dimensions. Clin. Orthop.: *17*, 38, 1960

MOTOSHIMA, T Studies on the strength for bending of human long extremity bones. J Kyoto Pref. Univ. Med *68*, 1377—1397, 1960.

NILSSON, B E. R: SMITH, R. E. The influence of breaking force of osteoporosis following fracture of the tibial shaft in rats. Acta Orthop. Scand: *40*, 72—79, 1969

OLIVO, O M, MAJ, G, TOAJARI, E Sul significato della minuta struttura del tessuto osseo compatto Boll Sc. Med Bologna: *109*, 369—394, 1937.

RABISCHONG, P, AVRIL, J. Role biomécanique des poutres composites os—muscles Rev. de Chir Orthop et Reparatrice de l'Appareil Moteur. *51*, 437—458, 1965

SEDLIN, E D: A rheologic model for cortical bone. Acta Orthop Scand.: suppl. *83*, 1965

SEDLIN, E D, HIRSCH, C. Factors affecting the determination of the physical properties of femoral cortical bone Acta Orthop Scand. *37*, 29—14, 1966

SMITH, J W., WALMSLEY, R.: Factors affecting the elasticity of bone. J. Anat.: *93*, 503—523, 1959

SNEDECOR, G W., COCHRAN, W G: Statistical Methods. The Iowa State Collage Press, 6th Ed, 1967

SWANSON, S A V., FREEMAN, M. A R: Is bone hydraulically strengthened? Med. & Biol Engng *4*, 433—438, 1966

SWEENEY, A W., KROON, R. P., BYERS, R K Mechanical characteristics of bone and its constituents. The Am Soc of Mech. Engineers Publ., 65-WA/HUF-7, 1965.

WEIR, J B de V., BELL, G H., CHAMBERS, J. W.. The strength and elasticity of bone in rats on a rachitogenic diet. J Bone & Joint Surg: *31 B*, 444—451, 1949.

WERTHEIM, M. G.: Mèmoire sur l'élasticité et la cohésion des principaux tissus du corps humain. Ann. Chim. Phys.: *21*, 385—415, 1847.
VOSE, G. P., KUBALA, A. L.: Bone strength—its relationship to x-ray determined ash content. Hum. Biol.: *31*, 262—270, 1959.
VOSE, G. P.: The relation of microscopic mineralization to intrinsic bone strength. Anat. Rec.: *144*, 31—36, 1962.
WRAY, J. B , GOODMAN, H. O.: Postfracture vascular changes and healing process Arch. Surg.: *87*, 801—804, 1963.

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FOREWORD

Medullary nailing is used throughout the world in all technically advanced countries. This method has defended its position extremely well through thirty years of experience and its use is increasing all the time. From the manufacturers we know that millions of these « medullary rods » have been sold.

The strength of the nail depends on its diameter. It increases with about the 4th potential of the transverse measurement. The medullary cavity is frequently too narrow to allow the introduction of a medullary nail of sufficient weight-bearing capacity. Not until *the method of widening the bone canal* with long drills was used, was it possible to produce a mechanically stable intramedullary osteosynthesis.

Since 1950 many surgeons engaged in traumatology, including members of the Swiss Arbeitsgemeinschaft für Osteosynthesefragen (A.O.), have used this technique. However, in many countries, for example U.S.A., the method is strongly opposed on the basis that it can cause considerable injury. Strangely enough *not one single experimental investigation has been published on this extremely important question* of reaming and nailing, in spite of the fact that this method has been used clinically for more than twenty years. The authors, S. Olerud, G. L. Lorenzi and G. Dankwardt-Lillieström, deserve great merit for the present research work and we owe them appreciation for penetrating the problem in such an extensive, precise and thorough way.

Gerhard Küntscher

INTRODUCTION

From the mechanical point of view it is of obvious advantage, as many surgeons realise, to treat certain diaphyseal fractures by the intramedullary nailing method. In earlier years, several different authors advocated various techniques of intramedullary fixation (Lambott 1913, Hey Groves 1918, Rush & Rush 1937). The method of Küntscher, however, has had the greatest success, and nowadays intramedullary nailing is generally linked with his name. It was in 1939 at a meeting of the Medical Society of Kiel that Küntscher first presented his concept of this procedure and introduced the spring-acting clover leaf shaped nail.

Eleven years later, in 1950, Küntscher proposed an important modification of this original method by introducing reaming of the medullary cavity. This meant that large contact surfaces between the nail and the inner cortex could be obtained, permitting the use of bigger and stronger nails. The size of the reamer used could also serve as a guide as to the most suitable diameter of the nail, and the risk of the nail getting locked was eliminated. Increased stability added to the value of this method and extended its use. The Küntscher type of intramedullary nailing, both with open and closed techniques and with different characteristics of the nail (Uffreduzzi 1942, Kaessman 1966, Weseley 1968, Schneider 1968), is still gaining increasing interest all over the world, 30 years after its introduction.

The principles of Küntscher-nailing are largely known and have often been emphasized by other authors, including Lorenz and Jorg Bohler. It seems surprising, however, that intramedullary nailing with reaming of the medullary cavity, which, though technically more extensive, is more stable and more efficient from the mechanical point of view, has not been more generally accepted by orthopaedic surgeons. But we consider that this relatively new idea, of reaming of the medullary canal, deserves deeper research in the experimental field. Danckwardt-Lillieström (1969*a*) found, on reaming, that marrow from

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LITERATURE REVIEW

Since 1940, after publication of Küntscher's first reports, nailing of shaft fractures has become an accepted method of internal fixation. Although nailing had been tried by several surgeons earlier, it was the principles of Küntscher which made it practically acceptable. His development of the method in 1950 by the reaming procedure must be considered very important, because of the possibility of primary weight bearing. During recent years, though very slowly, this change in the method has been accepted increasingly by many surgeons.

Although several studies have been published concerning the problem of nailing in different long bones of various animals, no report appears to have been made dealing with the problems arising on fracture treatment with true reaming of the medullary cavity including the inner part of the cortex. The reaming procedure involves complete destruction of the medullary circulation and gives rise to new problems regarding the blood supply to the bone as a whole and to the fracture site in particular.

The literature concerning these problems deals with such different and well defined questions that they can be suitably divided as follows.

1. Blood supply of the diaphyseal bone on nailing
2. Periosteal bone reaction after nailing
3. Reaming of the medullary cavity
4. Fracture stability on nailing.
5. Fracture stability and healing pattern.
6. Nailing and reaming in relation to fat embolism

1. Blood supply of the diaphyseal bone on nailing

As pointed out by several authors in the last 15 years, the blood supply of the shaft of long bones comprises three systems: 1. Peri-

the cavity easily caused blockage of the intracortical circulation. The effect of this on fracture healing after nailing is not known. The healing pattern, especially the peripheral bone reaction, seems at times to be contradictory—in spite of complete stability a large amount of callus formation is sometimes seen.

Our interest in the Küntscher nailing method inspired us to the present experimental studies. Although we realise that results from investigations on rabbits cannot be referred directly to man, our findings will make us more aware of the problems involved when we face clinical decisions.

There are still many unsolved problems concerning intramedullary nailing, and we hope that with this work we can give some answers to the following questions:

1. What kind and grade of damage do osteotomy and nailing produce in the cortical bone when the medullary cavity has been reamed?
2. How is revascularization of the cortical bone accomplished with a stable nail well fitting the marrow cavity?
3. How does the periosteal bone formation behave under these conditions?
4. How does repair take place in the fracture gap under these conditions?

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1 Blood supply of the diaphyseal bone on nailing.
2 Periosteal bone reaction after nailing
3 Reaming of the medullary cavity
4 Fracture stability on nailing.
5 Fracture stability and healing pattern.
6 Nailing and reaming in relation to fat embolism.

1 Blood supply of the diaphyseal bone on nailing

As pointed out by several authors in the last 15 years, the blood supply of the shaft of long bones comprises three systems: 1. Peri-

osteal vessels, 2. Nutrient arteries, 3. Metaphyseal vessels. The importance ascribed to these different pathways has varied.

Trueta and Cavadias (1964), in a study of the blood supply of long bones, arrived at the conclusion that (under their experimental conditions) the periosteal vessels were able to nourish only the outer third of the cortex. The same authors had stated in 1955 that the nutrient artery was normally responsible for the blood supply to the largest part of the cortex. De Marneffe (1951 and 1953) considered the proximal third of the tibia to be supplied mostly from the marrow canal. The distal third got its blood supply mostly from periosteal vessels and the middle third from both sources.

Brooks and Harrison (1957) believed that, perhaps because of the connection between the two systems, the circulation of the cortex would not be severely affected by suppression of one of the two systems (Koeckenberg 1963, Rhinelander 1968).

The damage that nailing of a long bone can produce in the medullary vascular system has been widely studied.

Trueta and Cavadias (1955), who were the first to study the small vessels in experimental nailed fractures, found, on microangiography, that even if part of the nutrient artery could escape damage, numerous branches were destroyed by the nail. In Göthman's experiments (1960*a*) with nailing alone, the arterial system was less severely damaged. When nailing was combined with fracture, he found more extensive damage to the intramedullary vessels (1960*c*).

The avascularity in the cortex that can sometimes result from nailing is obviously the reason for the cortical necrosis that some authors, e.g. Trueta and Cavadias, have shown to be very extensive and to persist partly even 8 months after the surgical procedure.

The inner avascular cortex, together with still viable bone, will undergo more or less extensive resorption and rebuilding activity, with formation of cavities. This rebuilding process has been described in recent literature by Koeckenberg (1963), Trueta & Cavadias (1964), Richany et al. (1965), Johnson (1966) and Danckwardt-Lilliestrom (1969*b*).

2. Periosteal bone reaction after nailing

The extensive periosteal bone formation so frequently observed by different authors, both clinically and under experimental conditions, has been given various explanations.

Küntscher (1940*b*-1941) considered that callus was formed as a

normal phlogistic response to the injury. Griessman (1944), Silani & Amanta (1949) and Maatz (1951) described in a clinical study the new bone formation all along the diaphysis. Their respective explanations were: the result of chemical or physical irritation, pressure of the nail against the bone, and vascular damage.

Trueta and Cavadias (1955) considered bone marrow ischaemia as a cause of the periosteal bone proliferation.

Gothman (1960*b*), in rabbits, found only an occasional profuse periosteal vascular reaction, and this was not accompanied by any new bone formation.

Koeckenberg (1963), like Trueta, considers that it may be due to damage to the intramedullary vessels.

Mital & Cohen (1966), in a study on rats, found that only with maximal injury in the medullary cavity was there any significant subperiosteal bone deposition.

Richany et al. (1965), in an investigation on cat femurs, destroyed the medullary cavity by introducing a pin into the canal. With further brushing and flushing the cavity was cleaned. In these experiments he found marked periosteal bone formation which he considered to be due to stasis in the periosteal vessels and oedema resulting from destruction of the medullary venous system. He remarked that the picture resembled that in hypertrophic pulmonary osteoarthropathy.

Zucman et al (1968) and Danckwardt-Lillieström (1969*c*) also observed periosteal bone formation, but because of their particular experimental conditions and of their original observations, their findings will be discussed under the next heading.

3 Reaming of the medullary cavity

Zucman et al (1968) destroyed the marrow tissue in the medullary cavity with a reamer in experiments on the rabbit tibia He gave a very clear description of the occurrence of bone marrow fragments under the periosteal layer during the reaming, and named this « *medullo hematoma* »

Zucman considered that bone marrow, pressed through the cortical channels to the subperiosteal space, played an important role as a bone marrow auto-transplant in promoting callus formation.

One of the present authors (Danckwardt-Lillieström, 1967 and 1969*c*) has also studied problems arising from reaming of the medullary canal Differently from Zucman et al., but also in the rabbit tibia,

he reamed in addition the inner part of the cortex, in an attempt to reproduce the same conditions as found in clinical practice.

Danckwardt-Lilliestrom (1969*a*, 1969*c*) confirmed the finding of Zucman of a subperiosteal « medullo hematoma », but he also demonstrated the intracortical and subperiosteal pathways of bone marrow by lipid staining methods.

Danckwardt-Lilliestrom (1969*c*) studied the correlation between periosteal bone formation and cortical avascularity. He showed that this was due to massive embolism of intracortical canals by bone marrow and fat.

The extent of the intracortical fat embolism and consequently of bone avascularity, is dependent upon the way in which the reaming is performed.

Danckwardt-Lilliestrom's studies (1969*c*) of the pressure in the medullary cavity during reaming of the rabbit tibia revealed wide variations from the normal value (30 mm Hg). With vigorous reaming, values up to 300 mm Hg could easily be obtained in the positive field. Negative values of about 100 mm Hg were recorded during withdrawal of the reamer.

It can be expected that reaming of a closed system such as the bone marrow cavity will result in such pressure changes.

The high pressure can easily explain the intracortical and subperiosteal presence of fat observed by Danckwardt-Lilliestrom (1969*c*) and Zucman et al. (1968), respectively.

We have demonstrated that as a consequence of reaming of the rabbit tibia, marrow fat particles can very easily appear in the femoral vein (Olerud et al. 1969)

4. Fracture stability on nailing

The aim of fracture treatment with intramedullary fixation has changed during the last few decades.

In previous years the only intention was to maintain the axial direction of the shaft fragments (Uffreduzzi 1942), and this always required further fixation with a plaster case. In time, however, this view altered, and more rigid stability with the avoidance of any complementary fixation became the main goal. Andersson (1962 and 1965) describes the two types of nails involved as « loose-fitting » and « tight-fitting ». We consider that in most cases the Rush pin method (1949) belongs to the loose-fitting type. The same is true of the Kirschner

pin (Landelius 1951), which was used extensively some years ago in the treatment of some diaphyseal fractures.

Satisfactory intramedullary fixation can be obtained by using a fascicle of metal pins (Hackethal 1961), with which the medullary cavity is filled completely.

In 1940 Küntscher developed a new nail, which in the transverse section worked as a spring. The aim was to obtain a nail which completely fitted the marrow canal. Küntscher found that much more stability was achieved by transforming the hour-glass shape of the medullary cavity into a cylindrical shape by reaming the inner cortex and using a wider and stronger nail (1950); at the same time the number of fractures that could be treated by this method increased.

Kaessman (1966 and 1969) describes a nail with still greater stabilizing properties especially concerning the rotatory forces, and with which compression can be applied to the fracture site.

Similar devices have also been described by Fitzgerald (1966) and Vinditti and Benini (1962).

Experimental studies of loose-fitting nails have been made by Göthman (1961), Gustilo et al (1964) and Rhinelander et al. (1967). Andersson (1965) compared the healing of experimental osteotomies in dogs with loose-fitting and tight-fitting nails Also Varma and Metha (1967) observed differences in healing between loose and tight fitting nails

5 Fracture stability and healing pattern

Since 1949, when Danis first proposed his compression plates, many authors have devoted their attention to problems of stability in the healing of fractures (Friedenberg et al. 1952, Yamagishi et al. 1955, Bagby et al 1958 and Petrokof 1962).

After the first reports from the AO-group with the paper of Schenck and Willenegger (1963), interest in this particular problem of osteosynthesis became intense and gave rise to considerable experimental and clinical research

Schenck & Willenegger (1963 and 1965), after stable compression plating of osteotomized dog radii, observed secondary osteones crossing the closely adapted fracture line They considered this an ideal form of bone healing (1967)

Geiser (1963), on the contrary, considered that the cortical fracture ends became rebuilt by « creeping substitution » from the endosteal and periosteal sides The same conclusion was drawn by Andersson (1965) and Rhinelander et al (1967)

Two of the present authors, Olerud and Danckwardt-Lillieström (1968 and 1970) also found the primary bone healing described by Schenk et al. possible in fractures fixed with compression plates in the dog tibia. This pattern of healing was only considered feasible with absolute contact of the fracture ends, where there was no room for transverse bone formation in the gap. In clinical practice it would therefore seem almost exceptional, according to these authors.

In those cases where there is a small fracture gap, the orientation of the new lamellar bone will initially be transverse. Later, it will assume a longitudinal direction as a result of the formation of longitudinal, secondary osteones traversing the fracture area.

The healing of a fracture treated with a loose-fitting nail, as studied experimentally by Göthman (1961), Andersson (1965) and Rhinelander et al. (1967), is usually delayed in comparison with tight-fitting nails, owing to severe necrosis of the fracture ends, with frequent non-union and an abundant formation of cartilage. Similar findings have been made by many other authors under almost similar experimental conditions (Silani et al. 1949, Trueta and Cavadias 1955, Koeckenberg 1963, among others).

Andersson (1965) planned his experiments with the purpose of comparing the healing of a fracture under the different conditions created by treatment with a loose-fitting and a fully-fitting nail. With the latter type of nail he noted more rapid healing with smaller areas of necrosis, only an occasional occurrence of cartilage and frequent direct bone formation.

Trueta et al. (1955) probably also obtained very stable fixation in many cases in his studies of intramedullary nailing of the rabbit radius, and in these cases, as is evident by his photographs, he always obtained the same results as Andersson. The choice of the radius for the osteotomy obviously ensured good stability because of the integrity of the ulna and the special connections between these two bones in the rabbit.

As far as clinical experience is concerned, Küntscher (1950) considered that the more stability that could be obtained the better healing would be achieved. Reaming of the canal before nailing, to make possible the use of a stronger nail, therefore seemed to him logical.

Nailing and reaming in relation to fat embolism

Heavy trauma, especially when resulting in fractures, always causes emboli of marrow fat in the lungs (Backer-Grøndahl 1911, Lehman

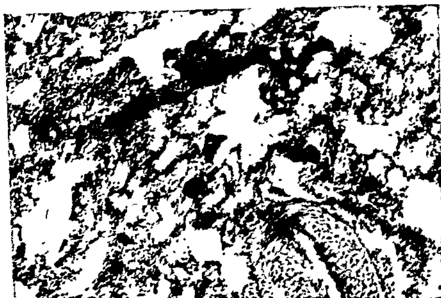


FIG 1. - Group NS Fat-stained marrow embolus in the lung



FIG 2 - Bone marrow appearing in the transparent catheter connected to the femoral vein during reaming

& Mc Nattin 1928, Grant & Reeve 1951). The liberation of fat in this way, and the biochemical and enzymatic effects of the traumatized fat tissue, which give the clinical entity of fat embolism, have been interpreted in different ways by different authors (Peltier 1956, Bergentz



FIG 3 - Fat supernatant seen as white flecks after centrifugation of blood collected from the femoral vein Note also the fat deposits on the walls of the test tube (to the right)

1961, Wehner 1968, Kerstell 1969, Saldeen 1969). It is conceivable that a large marrow embolus in the lungs might directly diminish the pulmonary circulation with a fatal outcome

Kerstell found, in experimental fractures in dogs followed by retrograde flushing of the lungs, that pulmonary fat embobi consisted only

of tissue fat and no plasma fat component. Küntscher is certainly aware of the risk of embolism and advocates very careful hammering of the intramedullary nail. Hackethal (1961) considers that the use of a tourniquet is always extremely important for the avoidance of

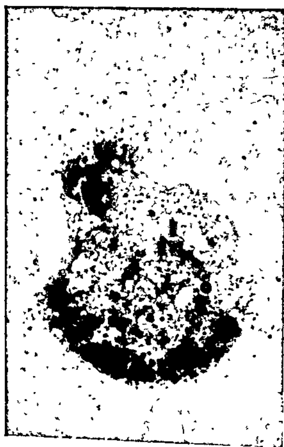


FIG 4 - May Grunvald-Giemsa staining of blood smear. Marrow conglomerates in the peripheral blood

fat emboli with the Bundelnagelungmethod. Peltier (1956) found a tourniquet useful in preventing fat emboli in orthopedic surgery.

Palmer (1951) and Bohler (1968) suggest that nailing should be avoided in all cases with signs of the fat embolism syndrome, so as not to develop it further.

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of tissue fat and no plasma fat component. Küntscher is certainly aware of the risk of embolism and advocates very careful hammering of the intramedullary nail. Hackethal (1961) considers that the use of a tourniquet is always extremely important for the avoidance of

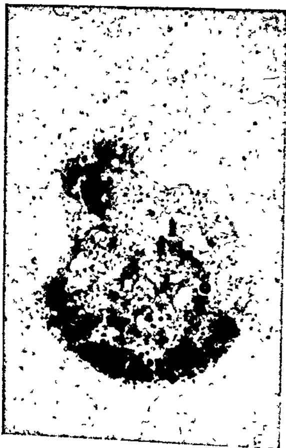


Fig 4 - May Grunvald-Giemsa staining of blood smear. Marrow conglomerates in the peripheral blood

fat emboli with the Bündelnagelungmethod. Peltier (1956) found a tourniquet useful in preventing fat emboli in orthopedic surgery.

Palmer (1951) and Bohler (1968) suggest that nailing should be avoided in all cases with signs of the fat embolism syndrome, so as not to develop it further.

& Mc Nattin 1928, Grant & Reeve 1951). The liberation of fat in this way, and the biochemical and enzymatic effects of the traumatized fat tissue, which give the clinical entity of fat embolism, have been interpreted in different ways by different authors (Peltier 1956, Bergentz



Fig 3 - Fat supernatant seen as white flecks after centrifugation of blood collected from the femoral vein. Note also the fat deposits on the walls of the test tube (to the right)

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MATERIAL AND METHODS

Premises

The studies of Danckwardt-Lillieström (1969*a-c*) mentioned above, with reaming of the rabbit tibia, showed that large areas of avascular cortex were produced, with considerable variation between different animals. The reason for this was found to be that marrow particles liberated by mechanical forces were pressed into the cortical canal due to an increase in intramedullary pressure which was produced during the reaming procedure, causing embolism and blockage of the cortical circulation (Fig. 5) and subperiosteal fat deposition (Fig. 6). In the following this investigation is referred to as experiment NS (Exp. NS).

In order to avoid such a pressure increase and to reduce the extent of marrow embolism, the medullary contents were evacuated by suction before and during the reaming through a drill-hole made in the ventral part of the distal tibial metaphysis (Danckwardt-Lilliestrom et al.,



Fig. 5 - Fat stained material filling the intracortical canals

Lange (1954) and Lechner and Schuster (1963) reported fatal cases, as also did Mörl (1967), who described 9 cases of fat embolism among 17 deaths out of 452 patients subjected to intramedullary nailing. Rokkanin et al. (1969) found cases of fat embolism, verified histologically by skin biopsies, among 116 cases of medullary nailing.

On reaming in clinical work Wehner (1968) observed a remarkable pressure rise in the medullary cavity.

On reaming under experimental conditions, Danckwardt-Lillieström (1969*a-c*) observed fat emboli caused by increased intramedullary pressure within the intracortical canals as well as in pulmonary tissue (Fig. 1).

Zucman (1968) describes the superiosteal medullo-hematoma after reaming of the medullary cavity.

On cannulating the femoral vein, Olerud et al. (1969) observed marrow tissue components in blood samples during a reaming procedure (Figs. 2, 3 and 4).

TABLE I.

Mean values, with standard deviations, of percentage of avascular cortex (PAC) in groups NS (non-suction group) and S (suction group), and also the differences in PAC between the groups, and their significance. The table also shows the number of animals in the respective groups.

Obs	Group *NS*			Group *S*			Difference *NS — S*	
time weeks	No of animals	PAC *M*	PAC ± *SD*	No. of animals	PAC *M*	PAC ± *SD*	*M*	*t*-value
1	11	21 5	15 68	5	6 2	3 40	15 3	3.22 **
2	15	20 7	14 33	5	7.1	1 95	17 6	3 54 **
4	14	16 1	12 50	2	1.6	0 79	15.4	4 33 ***

The table shows that the standard difference was very high in Exp. NS and very low in Exp. S. The figures for Exp. S show that revascularization took place between the second and fourth weeks. This process was completed more quickly in Exp. S than in Exp. NS. In the latter experiment similar values for revascularization were not attained until after eight weeks.

The investigation described above thus showed important differences within the cortical circulation between Exp. NS and Exp. S. In view of this finding it was considered important for the present investigation to distinguish between rabbits in which reaming was performed without previous evacuation of marrow tissue (Group NS) and those in which evacuation of marrow tissue preceded the reaming (Group S). In all the latter cases the reaming was performed with the utmost care and with continuous suction.

With these premises as a basis we started our experimental model.

MATERIAL

The investigation was carried out on 134 male and non-pregnant female albino rabbits, 7-8 months old and weighing 2.7-3.2 kg, with a mean weight of 3 00 kg. Experience had shown this size of rabbit to be ideal because of the thickness of the cortex and the width of the marrow cavity.

Our study concerned mainly the conditions of ideal healing of a stable osteotomy after reaming and nailing. For various reasons 86 of the 134 rabbits operated on had to be excluded from the main study,

1970). Under these conditions, in the following referred to as experiment S (Exp. S), the extent of intracortical avascularity, studied with Indian Ink microangiography on transverse tibial sections, was significantly smaller. A comparison was made between the findings in the two different experiments and the results are presented in Table I.



FIG. 6 - Fat stained transverse section Intracortical and subperiosteal fat is separating the periosteum from the cortex

The table gives the mean value and the standard difference for the percentage of avascular cortex in the two experimental groups after observation times of one to eight weeks. The difference between the values for the two series is also given for the different observation times. The degree of significance is denoted by asterisks.

solution (= approx. 30 mg Nembutal) per kg of body weight was injected into one aural vein and the needle was left in place for further maintenance doses during surgery if required. The animal was then fixed in position on a special sled-shaped operation table, as illustrated in Fig. 7.

TABLE II.

Observation time in weeks		Number of animals		Mean weight of each group before nailing (gram)		Change in weight at the end of observation time-mean value for each group (gram)	
S	NS	S	NS	S	NS	S	NS
1	—	4	—	2700	—	— 330	—
2	—	5	—	3100	—	00	—
—	2	—	2	—	3200	—	00
3	—	4	—	3100	—	100	—
4	—	4 **	—	2900	—	200	—
—	4	—	3	—	3300	—	300
6	—	3	—	2800	—	270	—
—	6	—	2	—	3100	—	140
8	—	3	—	2900	—	270	—
10	—	4 **	—	3000	—	950	—
—	10	—	3 *	—	3200	—	550
13	—	3	—	3100	—	100	—
—	13	—	4 *	—	2800	—	400
16	—	3 *	—	2700	—	1000	—
—	16	—	1	—	2800	—	(1500)
		Total number 33 − 15 = 48		Variation range 2500-3600			

* = indicates one rabbit treated with « Cerclage ».
S = medullary cavity suctioned
NS medullary cavity not suctioned

The fur was cut away and the skin cleaned and disinfected with antiseptic alcoholic solution. A curved incision was made, with a medial concavity extending from the upper part of the knee to the most distal part of the tibia, in this way exposing the entire anterior aspect of the tibia and the patellar ligament.

and therefore only 48 comprise the main material upon which the results are based.

The reasons for exclusion of the 86 rabbits will be discussed below under « Remarks on Operative Procedure » (Page 25) and « Post-operative complications » (Page 25).

The main material was grouped as follows:

Group S: Osteotomy and nailing after reaming during suction of the marrow cavity. This group consisted of 33 animals and was subdivided into 9 groups with observation times between 1 and 16 weeks.

Group NS: Osteotomy and nailing after reaming without suction. This group consisted of 15 rabbits, subdivided into 6 groups with observation times between 2 and 16 weeks.

The grouping and subgrouping of the 38 animals can be seen in Table II.

METHODS

After weighing, the rabbits were anaesthetized with Nembutal diluted in physiological saline in the proportion of 1:1; 1 ml of this

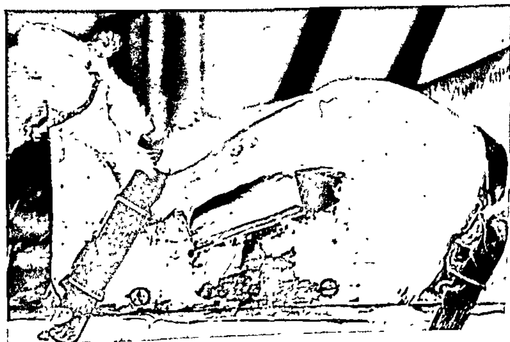


FIG. 7 - The rabbit's leg fixed on the special sledge

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1	—	4	—	2700	—	−330	—
2	—	5	—	3100	—	00	—
—	2	—	2	—	3200	—	00
3	—	4	—	3100	—	100	—
4	—	4 **	—	2900	—	200	—
—	4	—	3	—	3300	—	300
6	—	3	—	2800	—	270	—
—	6	—	2	—	3100	—	140
8	—	3	—	2900	—	270	—
10	—	4 **	—	3000	—	950	—
—	10	—	3 *	—	3200	—	550
13	—	3	—	3100	—	100	—
—	13	—	4 *	—	2800	—	400
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—	16	—	1	—	2800	—	(1500)
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Group S (Evacuation of marrow before and during reaming).

Using a drill 0.5 mm in diameter, a hole was made through the anterior aspect of the distal cortex in the tibia. A plastic transparent catheter with an inner diameter of 0.4 mm, connected to a suction apparatus was then inserted through the hole into the medullary cavity (Fig. 8*a*). During suction the catheter was repeatedly pushed up to the upper metaphysis, and at the same time physiological saline was poured over the distal hole. When no more bone marrow was

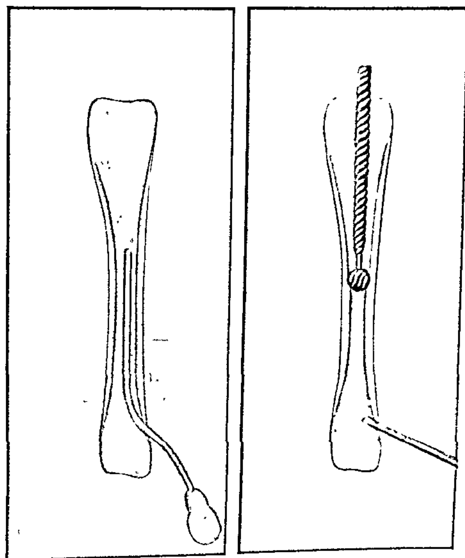


Fig 8 - *a*) Suction through a catheter in the distal hole *b*) Suction when reaming

seen to be sucked through the transparent catheter, this was again pushed up as far as possible and left there (Fig. 8*b*).

The patellar ligament was then divided longitudinally, and the precondylar space of the upper tibial epiphysis was exposed. A quadrangular awl was then inserted manually below the patellar ligament, through the metaphysis and into the upper end of the marrow cavity where the tip of the catheter was located.

Group NS (Direct reaming).

The same approach was made to the medullary cavity through the proximal tibia as in group S. No distal hole was made and no suction of the medullary cavity was performed prior to reaming.

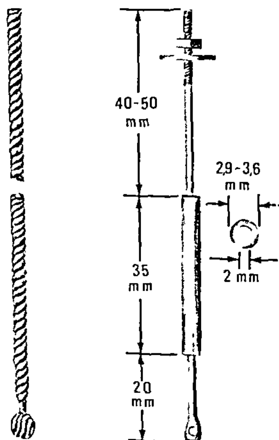


FIG. 9 - The characteristics of the reamer and the nail.

Group S (Evacuation of marrow before and during reaming).

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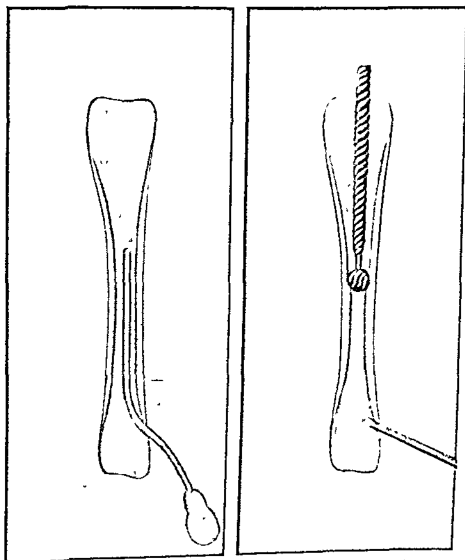


Fig. 8 - *a*) Suction through a catheter in the distal hole *b*) Suction when reaming

moistened with physiological saline, and great care was taken to avoid as far as possible any damage or stripping of the periosteum.

The nail was especially made from V.4.A. stainless steel (AISI 316). It was constructed as a compression nail for stability reasons (Fig. 9).

The nail had to be designed in such a way as to satisfy the following conditions:

a) The curved shape of the rabbit's tibia and the need for a certain degree of elasticity demanded that the nail be constructed in three different pieces.

b) The need for a nail which would completely fit the reamed cavity, at least at the fracture site, demanded a large cylindrical intermediate section with a diameter 100 μ smaller than that of the last-used reamer. Nails with different intermediate diameters were thus used in different animals.

c) The high rotatory forces in the rabbit's leg demanded that the curved dome shaped osteotomy should be stabilized with compression.

The osteotomy stumps were then apposed and the nail was inserted from the upper prespinal epiphyseal hole, with careful hammering on its head.

When the thicker part of the nail had engaged and fixed the osteotomy line, in group NS a hole was made 2-2.5 cm distal to the osteotomy line in the anterior aspect of the tibia.

Through this hole, and in that already existing in group S, it was possible to see the location of the end of the nail during hammering. A short pin was then passed through the cortical hole and through the distal hole in the nail and drilled into the posterior distal cortex of the tibia to fix and stabilize the nail.

The upper threaded head of the nail was then adjusted beside the patellar ligament and close to the epiphyseal plate. The nut at the top of the nail was tightened until complete stability was observed in the osteotomy line under intentional stresses.

The distal transverse pin was cut at the level of the outer cortex with a pair of steel scissors.

The patellar ligament was then sutured with single silk sutures. Only one suture was used for the tibial fascia. The skin was sewn with a continuous silk suture.

No dressings were applied to the wound, apart from a double layer

Reaming was then done in the same way in both experimental groups through the proximal hole, using ball reamers for dental surgery of diameters increasing from 1.3 mm to 3.7 mm. (For further details of the reaming technique, see Danckwardt-Lilliestrōm 1969*c*). The reamers were specially adapted and firmly mounted on a special steel spring shaft, 0.3 mm smaller in diameter than the reamer (Fig. 9). They were connected via a Jacob's chuck to an electric motor with a rotation rate of 300 r.p.m. The internal diameter of the marrow canal varies greatly in different animals even when they are of the same body weight and size.

After the first bone had been removed, two further reamers were used, of diameters increasing by 0.1 and 0.3 mm. This was done in an attempt to obtain as identical experimental conditions as possible.

In this way the amount of cortical bone removed by reaming was estimated to correspond to about 8% of the total bone surface (in the transverse section and the middle third of the tibia).

During the reaming procedure it was common in group NS to find the formation of a medullo-hematoma in the layer between the bone and the intact periosteum, as described by Zucman et al. (1968) and by Danckwardt-Lillström (1969*c*). This subperiosteal medullo-hematoma, in which Danckwardt-Lilliestrōm observed large amounts of fat, can occur almost anywhere around the tibia, but is more extensive just outside the openings for the nutrient arteries and emissary veins in the posterior, fibular part of the tibia.

Always during suction in group S, washing of the medullary canal was accomplished by pouring physiological saline through the upper precondylar hole, while the catheter was withdrawn to the level of the distal hole in the tibia but not taken out. This procedure with the catheter was also carried out during reaming In fact, all reaming in this group was done with a negative pressure in front of the reamer head.

With this technique temperature increases produced by the reamer were also avoided. No medullo-hematomas were ever seen in group S.

After reaming, the periosteum was divided transversally 0.5 cm distal to the tibio-fibular junction, leaving untouched only the anterior part covering the tibial crest, which was separated finally during the osteotomy

The osteotomy was performed at the same level with a goldsmith saw, the blade of which was 200 μ thick. To avoid rotation the osteotomy had to be done in the form of a curve with the convexity directed upward like a « dome ». During sawing, the bone was always kept

according to the technique described previously (Danckwardt-Lilliestróm 1969 c).

The treated left leg and the right leg were then removed and immediately deep-frozen. The greater part of the soft tissues was then removed without disturbing the periosteum, and the nail was withdrawn. The proximal and distal epiphyses were cut away and the specimens were freeze-dried until a constant weight was obtained (usually 3 days). Sections were then prepared by three different processes for examination:

1. Formalin fixation, nitric acid decalcification. Paraffin embedding, sectioning and preparation by the Spalteholz (1911) process for observation in a three-dimensional microscope.
2. Formalin fixation, nitric acid decalcification. (Paraffin embedding, sectioning and staining with the Masson technique.) Parts of the preparation were cut as frozen sections and stained with Sudan III and hematoxylin.
3. Methacrylate embedding. Sawing in longitudinal and transverse sections 0.5 mm thick, and grinding of these sections down to a thickness of between 20 and 60 μ for fluorescent light observation according to the technique described elsewhere (Olerud and Lorenzi 1969) To these undecalcified slide sections, the Goldner staining technique was also applied.

   The undecalcified ground sections were also studied with polarized light as well as by a microradiographic technique.

of plastic spray. In no case was plaster applied, nor any prophylactic antibiotic treatment given.

Recording methods

With special « Cristallite » Kodak X-ray film, roentgenograms were usually taken immediately after surgery and again at the end of the experiment after killing of the animal but before removal of the nail. Roentgenograms were also taken in most cases after removal of the nail. Only in the long term experiments were intermediate films taken, in order to check from time to time the healing of the osteotomy, the stability of the nail and the conditions of the bone. In all animals, at different times during the observation period, triple fluorochrome labelling was performed with Tetracycline, Hematoporphyrine and DCA Fluorescein, using the technique described elsewhere (Olerud and Lorenzi 1969 and 1970).

As shown in Table III, which gives the times of administration of the fluorochromes, the labelling of the newly formed bone covered 28 out of a total of 70 days of observation. At the end of the observation time the animals were anaesthetized again as described previously, and through a longitudinal midline laparotomy incision the abdominal aorta was exposed. This was cannulated with a plastic catheter 0.5 mm in diameter. Indian ink infusion was then performed

TABLE III.

Labelling code (L C.) according to which the rabbits were labelled with Tetracycline, Hematoporphyrin and DCAF [(N, N' di) carbomethyl, aminoethyl fluorescene] respectively

Observation time in weeks	Labelling day after the operative procedure		
	Tetracycline	Haematoporphyrin	DCAF
1	1	4	7
2	6	10	14
3	10	15	21
4	16	22	28
6	26	34	42
8	36	46	56
10	46	58	70
13	47	69	91
16	52	82	112

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   The undecalcified ground sections were also studied with polarized light as well as by a microradiographic technique.

RESULTS

Remarks on the operative procedure

Of the total 134 rabbits operated on, 6 died under anaesthesia, (no pulmonary biopsies were taken in these cases).

Forty animals were needed for trial operations to obtain the most suitable level and shape of the osteotomy. A curved osteotomy line was used to prevent rotation, which otherwise easily occurred. Owing to the tendency of the concave surface to become fractured, the concavity was made on the proximal fragment, which was mechanically stronger than the distal one, partly because of the greater extent of reaming in the distal fragment.

A level just below the tibio-fibular synostosis was chosen for the osteotomy. In this area the inner layer of cortex was always reamed, and therefore the nail always fit closely in both fragments.

Owing to longitudinal infractions in 7 rabbits, occurring in the proximal segment of the tibia during compression, a cerclage wire was added in these cases (5 in group S and 2 in group NS). No difference was observed in the healing pattern in these animals in comparison with the remainder. These 7 animals were therefore included in the main material

Postoperative complications

Fifteen rabbits sustained secondary fractures, mostly longitudinal in the upper part of the tibia, during the first days after operation, and they were therefore excluded from the material.

During the observation period 19 rabbits died of epidemic gastro-intestinal infection with diarrhoea.

In group S no local infection occurred, nor any deaths from fat emboli.

In group NS there were 2 deaths from massive local infections and also 4 deaths from massive fat emboli, verified histologically. Of these latter 4 rabbits, one died just before the end of the operation and 3 during the first hours postoperatively. These deaths from fat

emboli, which thus occurred only in group NS in which reaming was performed without suction, comprised 11% of the total operated on in this group. During operation in this group a further 4 animals developed sudden dyspnoea and cyanosis. It seems highly likely that pulmonary fat emboli occurred also in these animals, which later recovered spontaneously.

General body reaction to the operation

The change in the mean body weight was calculated in each subgroup of groups S and NS (see Table II, p. 17). During the first week the body weight decreased in both groups. After the third week the animals in group S showed a fairly even and continuous weight increase. In group NS the body weight increase was usually slower than in group S. Also the death rate indicates that the animals in group NS were more severely affected than those in group S.

Local reactions

During the first 24 hours after operation, the rabbits held the treated leg close to their body, but after this time they seemed to use their legs in the normal way.

In group S the local reaction in the undisplaced osteotomized legs was characterized by a small spool-shaped swelling which decreased after 2-3 weeks and developed into a very small bony prominence. In group NS the swelling was more pronounced and the spool shape more elongated. After the 2nd to 3rd week the swelling was still considerable and became indurated. The time it took for the swelling to decrease was much longer in group NS.

Roentgenological findings

In most of the rabbits a good fit of the nail in the reamed cavity was seen (Fig. 4). The curved osteotomy line was hardly visible even in the short-term experiments. In the distal part of the tibia it was also possible to compare the thickness of the reamed cortex and the non-reamed cortex, and the amount of cortical bone removed could be roughly estimated (Fig. 10). Figure 11 demonstrates the shape and level of the osteotomy line in an animal observed after the 2nd week, where the gap is widened because of the absence of callus and the movement during withdrawal of the nail. The cerclage-treated animals showed no difference in the roentgenological findings from the unfractured cases (Fig. 12).

The roentgenological healing pattern differed regularly in groups S and NS (Fig. 13). In the animals with late secondary fractures (Fig. 14) it was more difficult to distinguish between the two groups.



Group S (with suction)

The peripheral osseous formation in this group was, as a rule, very thin and was observed only at the level of the osteotomy and never along the whole tibia (Fig 15).

The fracture line was only slightly visible after 4 weeks and in most cases had completely disappeared after 8 weeks (Fig. 16*a*-*b*). Endosteal bone formation was nearly always present and locked the nail. This could be regarded as a sure sign of complete stability (Fig. 17).

The porosity of the cortical bone as a sign of cortical remodelling which took place in the later stages of the healing can be seen in Fig. 17.

FIG. 10 - X-ray appearance just after operative procedure

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Fig. 13 - Schematic illustration of the roentgenological observations. *A* refers to the observations in group S. *BI* and II refer to the observations in group NS.

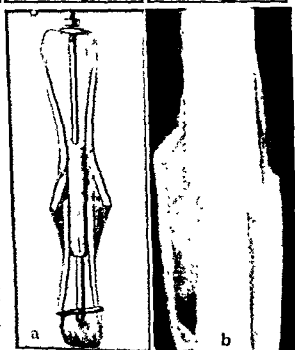


Fig. 14 - *a*) Schematic illustration of healing after secondary fracture. *b*) X-ray 6 weeks after nailing.



FIG. 11. - X-ray. The osteotomy line 2 weeks after operation.

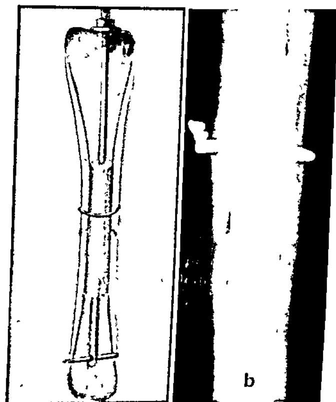


FIG 12 - *a*) Schematic illustration of the healing after nailing and « cerclage » *b*) X-ray of rabbit in group S 10 weeks after nailing



Fig 16. - Group S X-ray 4 weeks after nailing. Almost no peripheral reaction. Osteotomy line is hardly visible (*a*) 8 weeks after nailing: Osteotomy line still less visible (*b*)



Fig 17 - Group S. X-ray 10 weeks after nailing a bone cast around the nail gives a negative image of the nail The porosity of the cortex in the later stages can be seen here.

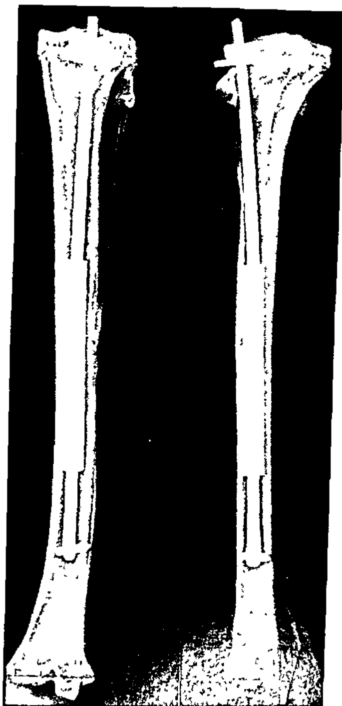


Fig. 15. - Group S X-ray 8 weeks after nailing, showing a small thickening of the bone at the osteotomy site.

Groups NS (*without suction*)

The peripheral osseous formation, illustrated in Fig. 18, was often considerable and extended along the *entire diaphysis. Sometimes* it was interrupted at the fracture level (Fig. 20). A similar, but not quite so extensive *peripheral bone reaction* is shown in Fig. 19. Condensation of the new peripheral osseous tissue, which had the appearance of a new cortex, was observed in this group (*Fig. 18*). *The* original cortex appeared to be sequestrated and this was most pronounced close to the fracture line. *The resorption* of cortex was more pronounced far away from the osteotomy line.

The cortical ends, in contact at the osteotomy line, seemed to be practically unaffected by resorption. In some cases (Fig. 21) the peripheral new bone did not bridge the osteotomy line in spite of the



FIG. 16. - Group S. X-ray 4 weeks after nailing. Almost no peripheral reaction Osteotomy line is hardly visible (*a*). 8 weeks after nailing: Osteotomy line still less visible (*b*)



FIG 17 - Group S X-ray 10 weeks after nailing a bone cast around the nail gives a negative image of the nail The porosity of the cortex in the later stages can be seen here



Fig 18 - Group NS X-ray 6 weeks after nailing. A considerable peripheral reaction is visible all along the diaphysis, which is undergoing corticalization while the old cortex seems to be sequestrated. On the right the contralateral tibia

good stability which still seemed to exist, as indicated by the relatively unaffected cortical ends. In spite of the good apposition and stability achieved during surgery and which was still effective even after 10



Fig 19 - Group NS X-ray 10 weeks after nailing: the extensive peripheral reaction is larger at the osteotomy site. A pseudarthrosis is developing, and in this case the stability appears to be poor.

weeks in most cases, there was no satisfactory bridging across the osteotomy line.

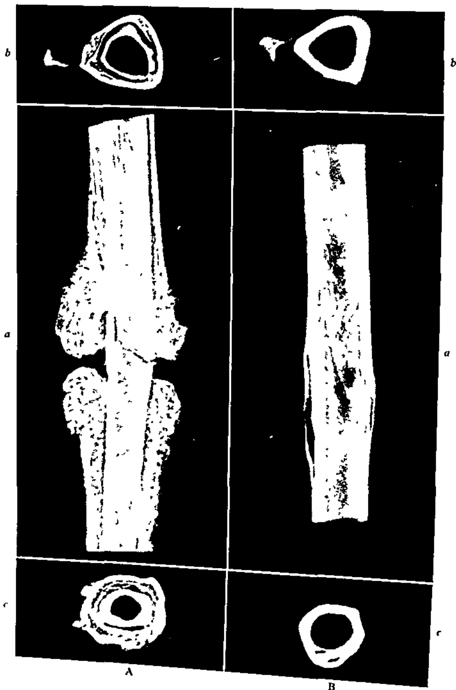
Almost all animals in group NS (BI and BII in Fig. 13) could be considered to show delayed union, at least, even if not true non-union (Fig. 21)



Fig. 20. - Group NS. X-ray 13 weeks after nailing: another extensive, *less mature*, peripheral reaction and delayed union. On the right the contralateral tibia.

Fig. 21 A. - Group NS. X-ray 10 weeks after nailing *a*) Pseudarthrosis. The old sequestrated cortex appears to be still in contact and well adapted. Note the corticalization of the peripheral osseous reaction *b*) and *c*) Transverse section of upper and lower diaphysis. The central part of the cortex is sequestrated.

Fig. 21 B - Group S. X-ray 10 weeks after nailing *a*) Well healed osteotomy. *b*) and *c*) Transverse section of upper and lower diaphysis


b
b
a
a
c
c
A
B

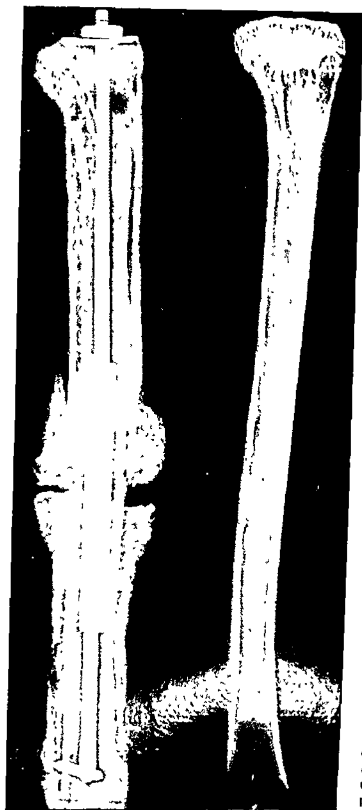


Fig. 20. - Group NS. X-ray 13 weeks after nailing: another extensive, less mature, peripheral reaction and delayed union. On the right the contralateral tibia.

Fig. 21 A. - Group NS X-ray 10 weeks after *nailing. a)* Pseudarthrosis. The old sequestrated cortex appears to be still in contact and well adapted. Note the corticalization of the peripheral osseous reaction. *b)* and *c)* Transverse section of upper and lower diaphysis. The central part of the *cortex is sequestrated.*

Fig. 21 B. - Group S X-ray 10 weeks after *nailing a)* Well healed osteotomy. *b)* and *c)* Transverse section of upper and lower diaphysis.

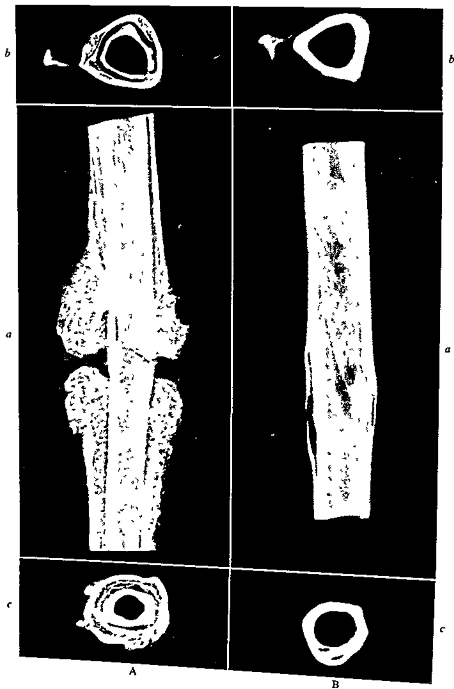

b
b
a
a
c
c
A
B



Fig. 20. - Group NS. X-ray 13 weeks after nailing: another extensive, less mature, peripheral reaction and delayed union. On the right the contralateral tibia.

Fig. 21 A. - Group NS. X-ray 10 weeks after nailing *a*) Pseudarthrosis. The old sequestrated cortex appears to be still in contact and well adapted. Note the corticalization of the peripheral osseous reaction *b*) and *c*) Transverse section of upper and lower diaphysis. The central part of the cortex is sequestrated

Fig 21 B - Group S X-ray 10 weeks after nailing *a*) Well healed osteotomy. *b*) and *c*) Transverse section of upper and lower diaphysis

The first vessels very soon grew into the peripheral avascular part of the cortex, however, even at the level of the osteotomy line where the periosteum had been separated from the cortex during surgery and been replaced before closure of the wound. Around the vessels

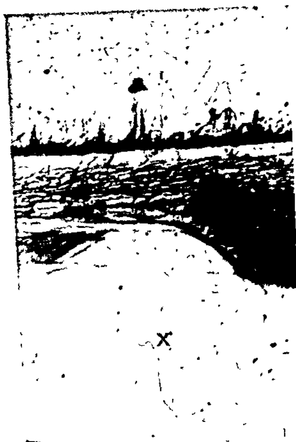


FIG 23 - Group S Spalteholz preparation 4 weeks after nailing Almost normal intracortical circulation at the upper nail level, where the endosteal circulation is also well re-established.

penetrating the avascular cortex there was progressing resorption, seen mainly in the third and fourth weeks (Fig. 24*a* and *b*). Later in the healing process the revascularization activities involved the development of many cutter heads which usually passed through the cortex in the direction towards the osteotomy line (Fig. 25) Sometimes

Microscopical observations

Vascularity and rebuilding of cortex

The experimental procedure always resulted in total damage to the *intramedullary circulation*, and close to the osteotomy line also in periosteal damage. This damage, due to stripping of the periosteum around the osteotomy, was estimated to extend about 1 cm above and 1 cm below the osteotomy line. This meant total primary avascularity of the osteotomy area.

Group S

In one preparation observed after one week the cortical ends were completely avascular (Fig. 22). In the distal and also, mostly, in the upper part of the diaphyseal cortex, far away from the osteotomy



Fig 22 - Group S Spalteholz preparation 1 week after nailing Complete avascularity of the cortical ends A vascular loop is entering the osteotomy line × Medullary cavity

line, it was common to observe an *almost normal intracortical circulation* (Fig. 23). During the first week the intracortical vassels became wider. The vascular front was located at the level of the damaged and undamaged periosteum.



FIG. 25. - Group S Fluorescence preparation 4 weeks after nailing (L C. 16-22-28). Cutter heads are remodelling the cortex and progressing towards the osteotomy line



FIG 26 - Group S Fluorescence preparation 8 weeks after nailing (L C. 36-45-56) Remodelling of the cortex. From resorption cavities (red and green) new canals (green) are moving along the cortex





Fig 24 - Group S Fluorescence preparation 3 weeks after nailing (L C. 10-15-21)
a) Penetration and widening of vascular canals from the periosteal area The vessels are directed towards the nearby osteotomy line located to the right
b) The same appearance in a transverse section.



FIG 25 - Group S. Fluorescence preparation 4 weeks after nailing (L C 16-22-28) Cutter heads are remodelling the cortex and progressing towards the osteotomy line.



FIG 26 - Group S Fluorescence preparation 8 weeks after nailing (L C 36-45-56) Remodelling of the cortex From resorption cavities (red and green) new canals (green) are moving along the cortex.





FIG 27. - Group S Spalteholz preparation 6 weeks after nailing *a)* Abundant intramedullary vascularization has reached the upper part of the nail The vessels are beginning to supply the inner cortex and to join the peripheral circulation *b)* The transverse section also shows the small upper nail pin embraced by the new bone × indicates the site of the nail



FIG. 28. - Group S. Spalteholz preparation 6 weeks after nailing. Abundance of vessels attacking the inner avascular cortex just adjacent to the nail.

these cutter heads, supplied by vessels coming from the periosteum, seemed via resorption lacunae to excavate the cortex, often the middle part (Fig. 26). The cortex could be revascularized from endosteal vessels in some cases as early as in the 2nd and 3rd weeks, but the 4th week was more usual for revascularization from this direction. These vessels penetrated the cortex especially in the region above the upper end of the nail (Fig. 27*a* and *b*). They often gave rise to resorption at the inner wall of the cortex and revascularized the inner part of it (Fig. 28).

Group NS

The avascularity of the cortex in this group was often very extensive. It was caused not only by the rupture of marrow vessels but also by marrow fat particles which had been forced out into the intracortical canal system. The avascularity lasted for a very long time. In a preparation six weeks after osteotomy there were still large areas without any Indian-ink filled vessels (Fig. 29).

The revascularization process of the cortex appeared to be quite different from that in group S, although in some cases the invasion of blood vessels from the periosteum close to the osteotomy line was similar.



FIG. 29*a*. - Group NS. Spalteholz preparation 6 weeks after nailing. Revascularization pattern. From top to bottom. 1) Outer corticalized peripheral layer; 2) large vascular lacunae; 3) vascular communications with outer revascularized cortical layer; 4) sequestrated inner cortex.



FIG. 29*b*. - Transverse section of preparation in Fig 29*a*

In comparison with group S, only a few vessels seemed to enter the cortex. Other vessels joined in cavities to form wider sinusoids often located in the middle part of the diaphyseal cortex. These vascular cavities increased in size and became more elongated along the cortex, forming a kind of reticular system. The cortical bone seemed to become « dissolved » or « melted down » in a peculiar way. This resorption procedure did not present the typical appearance of pure osteoclastic activity.

In its most pronounced form this « melting » activity would divide the cortex into one central layer which in some cases was sequestrated



FIG 30 - Group S Fluorescence preparation 2 weeks after nailing (L.C. 6-10-14) The red labelling shows the first bone deposition under the stripped periosteum after ten days The activity has increased very rapidly during the next days and the bone is labelled with green on the 14th day.

completely (Fig. 29) and one outer layer which would later be included in the remodelling of the new cortex in one way or another (Fig. 29).

Periosteal bone formation

Close to the gap, where the periosteum had been incised, ingrowing vessels and cells from surrounding tissues contributed to bone

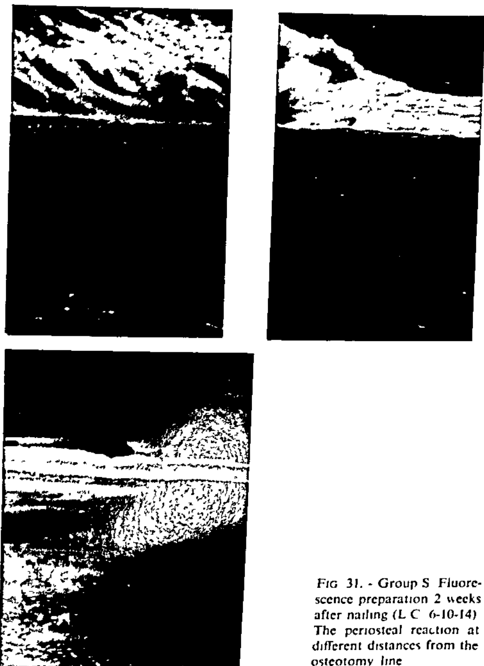


FIG 31. - Group S Fluorescence preparation 2 weeks after nailing (L C 6-10-14) The periosteal reaction at different distances from the osteotomy line

formation. Away from the osteotomy line the bone was only formed subperiosteally.

Group S

In this experimental group the new bone reached a limited thickness only close to the level of the osteotomy line. The first periosteal reaction was seen to have occurred on the 3rd to 4th day in the hematoporphyrin-labelled bone, up to a distance of 0.5 cm from the osteotomy line. This newly formed bone often bridged the osteotomy line after the first week (Fig. 30). In the 1st and 2nd weeks it had the typical appearance of trabecular bone, later usually forming primary osteones in several layers. From the level of the osteotomy line, these osteones decreased in number and thickness along the diaphysis and finally ended in a layer of superficial lamellar bone far away from the osteotomy line (Fig. 31). Later, in the 6th to 8th weeks, the outer layer of trabecular bone underwent remodelling by superficial resorption of the ridges and by lamellar bone formation around the vessels in the intertrabecular spaces, a process which resulted in condensation, or corticalization, of the outer layer of the periosteally formed bone (Figs. 32 and 33). In the innermost layer just outside the cortical bone and close to the osteotomy line, resorption activities predominated, with typical Howship's lacunae eroding the outer cortex and resorption of the inner part of the newly formed trabecular bone (Fig. 33). This process terminated in the formation of limited cavities which then tended to unite. The tendency of these cavities was to move slowly into the cortex as a result of resorption from the central cortical wall and accretion of bone to the inner side of the peripheral wall.

Group NS

The periosteal bone formation was always very pronounced all along the diaphysis (Fig. 34). In comparison with group S, the bone formation began some days later. In some cases it showed even distribution along the diaphysis, but in the early stages it was also possible to see parts of the bone without any subperiosteal bone formation. Close to the osteotomy line, newly formed bone was seldom seen on the surface or in the gap. This was observed, however, in one preparation after 2 weeks (Fig. 35). During the time up to the 4th week the newly formed periosteal bone could reach enormous proportions, in some cases up to 8 times as much as observed in group S (Fig. 34).

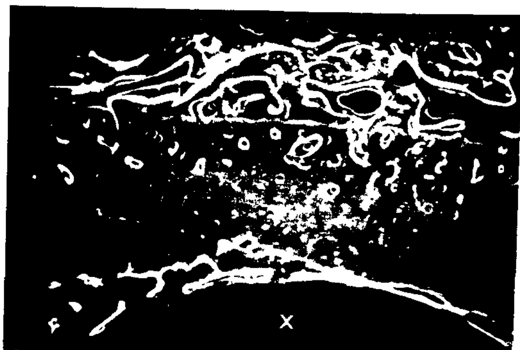


FIG. 32. - Group S. Fluorescence preparation 6 weeks after nailing (L.C. 26-34-42). The outer peripheral reaction is undergoing resorption. Condensation is clearly demonstrated by the triple fluorochrome linear labelling. In the inner part just in contact with the nail a layer of green labelled bone can be seen



FIG 33 - Group S Fluorescence preparation 6 weeks after nailing (L C 26-34-42) Resorption cavities in the inner part of the peripheral bone

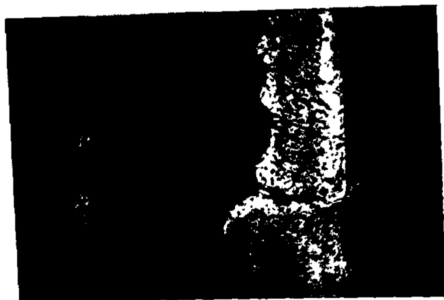


FIG 34 - Group S (left). Fluorescence preparation 4 weeks after nailing The enormous peripheral reaction in group NS (right) attains almost 8 times the size of that observed in group S (L C. 16-22-28) The arrow indicates the osteotomy line



FIG 35 - Group NS Fluorescence preparation 4 weeks after nailing (L C. 16-22-28). At the fracture line the periosteal bone formation is interrupted by vascular granulation tissue with wide resorption areas Note the large vessels

This bone consisted of long spicular trabeculae. Close to the fracture gap these trabeculae were orientated towards the gap, but further away along the diaphysis the orientation was perpendicular to the cortex as if very strong bone induction was taking place.



FIG. 36. - Group NS. Fluorescence preparation 6 weeks after nailing (L. C. 26-34-42) Bridging external callus, no activity in the fracture ends.

The periosteal reaction gave newly formed woven bone, which moved like a wave towards the osteotomy level with increasing observation time. In between the « waves » from each side, fibrous tissue, large vessels (Fig. 35) and sometimes cartilage cells were seen. This observation could, of course, be interpreted as a demonstration of instability, but very often, in other parts of the same tibia, periosteal



FIG 37. - Group NS Fluorescence preparation 13 weeks after nailing (L.C. 47-69-91) Peripheral bridging corticalization. Rebuilding and sequestration of old cortex At the bottom the site of the nail is seen.

callus could be seen to bridge the osteotomy line (Fig. 36). In the following weeks, beginning from the end of the 6th, the newly formed periosteal bone underwent final maturation. Outside the osteotomy gap, this process followed the same pattern and stages as in group S. The bone maturation and formation of cystic resorption cavities showed only quantitative differences (Fig. 37).

Intramedullary reaction

When reaming, owing to the irregular shape of the medullary cavity, only parts of the innermost cortical layers will be removed (Fig. 38) The *a* zones (see figure) of the medullary cavity are not totally removed by the reamer, but obviously the vessels there must be severely damaged. The nail itself usually fits very well in the distal part of the canal, but will be free from contact with the cortex at several points in the upper part of the diaphysis (Fig. 38).

The revascularization of the medullary cavity and of the inner part of the cortex usually follows three pathways:

1. from the undisturbed upper and lower metaphysis along the *a* zones,

This bone consisted of long spicular trabeculae. Close to the fracture gap these trabeculae were orientated towards the gap, but further away along the diaphysis the orientation was *perpendicular to the* cortex as if very strong bone induction was taking place.



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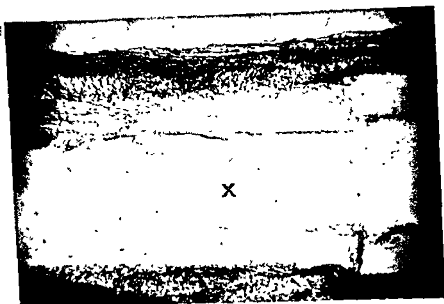




Fig 39 - Group S Spalteholz preparation 2 weeks after nailing *a*) The extent of the avascularity is well demonstrated Abundant peripheral vascular reaction. Single blood-vessel branches are passing into the osteotomy gap (bottom right). From the proximal fragment the vascular front is progressing together with intermedullary vessels (top left) *b*) Enlargement of the former pictures (Lower osteotomy line)

2. directly through the cortex, mainly observed in the upper part of the diaphysis,
3. through the fracture gap where such exists.

Group S

The appearance of vessels in the medullary cavity, growing through the gap, was already observed after the first week (Fig. 39*a* and *b*). A network of vessels in the *a* zones, partly coming from the upper

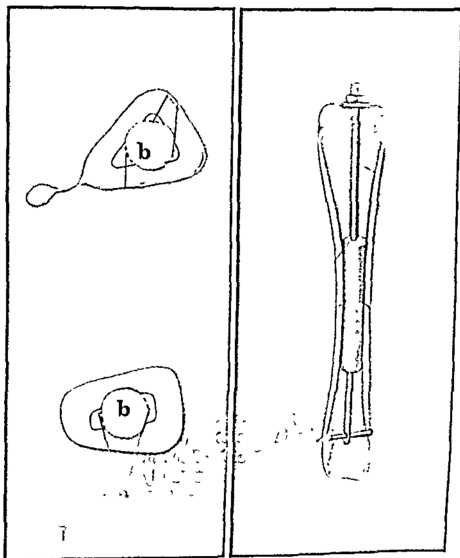


FIG. 38. - Schematic diagram illustrating: I) reamed areas of inner cortex (*b*) and non-reamed parts of the medullary cavity (*a*); II) the fitting of the nail and the free zones where the medullary circulation has free space.

end, was seen after the third week. At the same time, single vessels appeared in the *b* zones between the reamed cortex and the nail.

From the third week onwards newly formed bone was seen in the *a* zones immediately adjacent to the nail. The progression of bone formation in the section shown in Fig. 40 can easily be timed. Common also was the observation of vessels directly crossing the cortex and growing almost as far as the nail where they sometimes divided in the form of a T, which embraced the nail (Fig. 41). The further remodelling of the cortex proceeded in a typical manner, consisting of erosion of the inner cortical layer with simultaneous deposition of lamellar bone around the nail (Fig. 42).



FIG 42. - Group S Fluorescence preparation 4 weeks after nailing (L C. 16-22-28) Remodelling of the inner cortex with simultaneous erosion and deposition of bone lamellae along the nail Note the rebuilding in the outer cortex (bottom)

The process of erosion of the inner part of the cortex resulted in the confluence of many different cavities surrounding the newly formed bone around the nail (Fig. 43). These cavities contained blood vessels and new bone marrow with marrow cells and fat cells. The vessels, often as large as vascular lacunae, frequently seemed to be in communication with the metaphyseal vascular system, which, after the



FIG. 40 - Group S. Transverse section. Fluorescence preparation 4 weeks after nailing (L.C. 16-22-28). Newly formed bone enclosing the nail is labelled with yellow (zone *a*), red and green (zone *b*). Note the resorption of peripheral ridges.

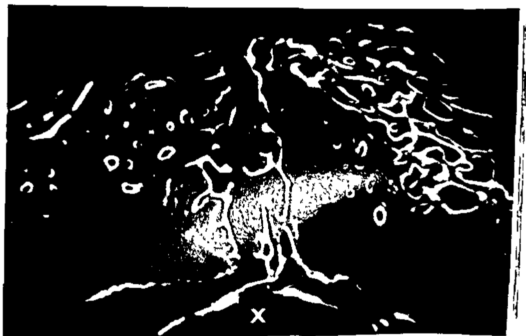


FIG. 41. - Group S. Transverse section. Fluorescence preparation 8 weeks after nailing (L.C. 36-46-56) Centrally a large vessel with a lacunar appearance is traversing the cortex and divides into two branches embracing the nail Intense remodelling in the outer part of the cortex.

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4th week, usually took a more active part in the supply of the inner cortex with blood vessels (Fig. 44). In still later stages the new bone around and close to the nail became thicker, and also acquired a more mature appearance (Fig. 45).

Group NS

The intramedullary reaction in this group was usually extremely delayed, except in some rare cases, where the intracortical circulation had not been so severely disturbed (compare zone *a* in Fig. 38 I).



FIG 43. - Group S. Transverse section Fluorescence preparation 10 weeks after nailing (L.C. 46-58-70) Maturation of the inner cortex with confluence of erosion cavities Lamellar bone around the nail



FIG 44. - Group S. Fluorescence preparation 4 weeks after nailing (L C. 16-22-28) Revascularization of the inner cortex from vessels between the nail and cortical wall.



FIG 45 A - Group S Fluorescence preparation 13 weeks after nailing (L C. 47-69-91). Locking of the nail. Left · longitudinal section shows the upper part of the cast which consists of matured bone well attached to the cortical wall by large beams Right distal transverse section demonstrates the stability of the nail. Note the spongy appearance of the middle cortex.

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FIG. 44 - Group S Fluorescence preparation 4 weeks after nailing (L.C. 16-22-28) Revascularization of the inner cortex from vessels between the nail and cortical wall.

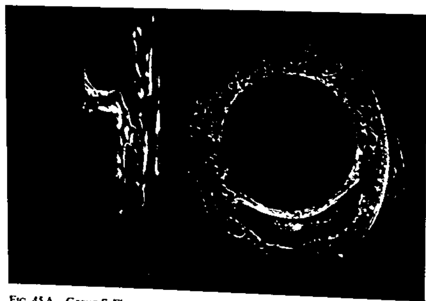


FIG 45 A - Group S. Fluorescence preparation 13 weeks after nailing (L.C. 47-69-91). Locking of the nail Left: longitudinal section shows the upper part of the cast which consists of matured bone well attached to the cortical wall by large beams. Right distal transverse section demonstrates the stability of the nail. Note the spongy appearance of the middle cortex.

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The nail and the bone formation

Group S

Very soon after the vessels reached the nail, usually in the 3rd or 4th week, it became surrounded by newly formed bone (Figs. 40, 42 and 44) which increased successively in amount and maturation (Fig. 43). The bone formed a cast, so to speak, which embraced all three parts of the nail (Fig. 45 A and B). This bone cast around the nail can be regarded as an expression of the total stability of the fixation system.



FIG. 45 B. - Corresponding preparation investigated with microradiography. Note the well adapted bone cast of the nail.

Group NS

Up to the 10th week no new bone was usually formed around the nail in this group. In sections examined after the 13th week, incomplete bone casts with a considerable amount of fibrous tissue between the bone and the nail were found. This finding can probably be regarded as a sign of instability.

Osteotomy line

The intramedullary nail, because of its central position, should be the ideal device for achieving equal compression all along the circumference of the contact surfaces of the osteotomy. This condition was not always obtained in our experiments. This was partly due to the slightly curved shape of the rabbit tibia in the longitudinal axis, while

the nail was purely cylindrical and was unable to bend in its central part. The curved osteotomy itself cannot always be ideal for good apposition in spite of the fact that it prevents rotation. For these reasons we usually observed in the same animal an osteotomy which was well apposed and had complete contact on the one side of the tibia, but with a gap on the other side.

Group S

The first signs of healing of the osteotomy line started with vascularization. Vessels could appear in the gap as early as in the first week (Fig. 46). When the bone contact is absolute, vascular invasion from the periosteal side is very difficult. In these areas an ingrowth of



Fig. 46 - Group S. Fluorescence preparation one week after nailing (L.C. 1-4-7). In the well adapted osteotomy line a tiny vessel is proceeding

The nail and the bone formation

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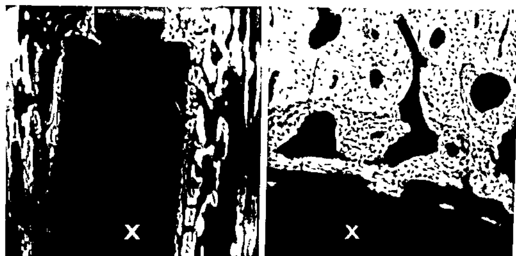


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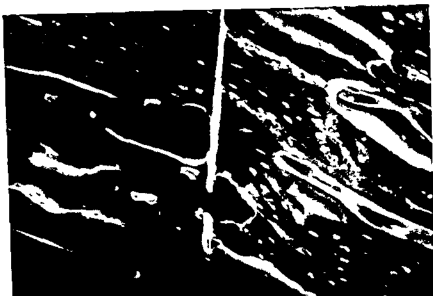


FIG 48 - Group S. Fluorescence preparation 6 weeks after nailing (L.C. 26-34-42) Secondary osteones are approaching the osteotomy line, and cutter heads stop at the line to produce an «elephant foot» formation.

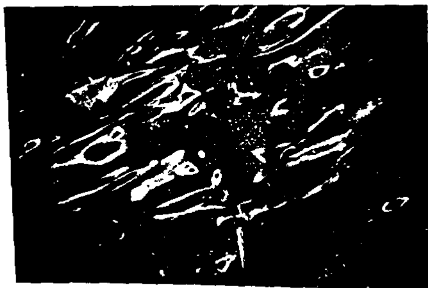


FIG 49 - Group S. Fluorescence preparation 6 weeks after nailing (L.C. 26-34-42) The healing is almost completed in the outer layer of cortex The innermost part, where the last osteone has passed through, is still undergoing remodelling.

vessels with simultaneous bone resorption was not observed before the 3rd week. This resorption was almost immediately followed by formation of lamellar bone in the form of primary osteones. The resorption area was U-shaped with formations resembling cutter heads, occurring on both sides of the line, which was often respected as if resorption of the fracture surfaces was more difficult (Fig. 47). The



FIG 47. - Group S. Fluorescence preparation 6 weeks after nailing (L C. 26-34-42). *U*-shaped area of resorption and deposition of the cutter head type

osteotomy line, filled out in this way by bone, was later crossed by secondary osteones in the 5th to 6th week.

The U-shaped bone remodelling with resorption and bone formation in the gap eventually connected the two fracture ends. This

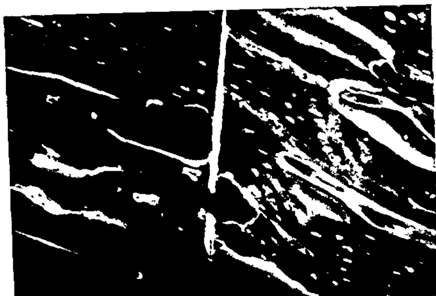


FIG 48 - Group S Fluorescence preparation 6 weeks after nailing (L.C. 26-34-42) Secondary osteones are approaching the osteotomy line, and cutter heads stop at the line to produce an «elephant foot» formation



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osteotomy line, filled out in this way by bone, was later crossed by secondary osteones in the 5th to 6th week.

The U-shaped bone remodelling with resorption and bone formation in the gap eventually connected the two fracture ends. This

After the 10th week most of the osteotomy line was filled with new transversely formed bone, and many longitudinal osteones crossed the osteotomy line, including that part where there was close contact. In this way the remodelling of the osteotomy line would become completed, even if some small parts of it remained unchanged for a very long time (Fig. 49 and 50).



FIG 51. - Group S Fluorescence preparation 3 weeks after nailing (L C. 10-15-21) Wide osteotomy gap early invaded by vessels. Yellow labelled bone (10th day) is seen at the entrance of the gap Lamellar bone is deposited during the red through green period Note the retrograde vascularization of the cortical ends.

The wide gap was quickly invaded by new vessels coming from the network produced by the peripheral vascular reaction. Primarily

process came to a stop in its progression along the osteotomy line, after which the newly formed bone underwent maturation. Parts of the closely adapted osteotomy line remained unchanged until it became rebuilt by traversing secondary osteones. Termination of the revascularization process was a very frequent finding and we cannot give any acceptable explanation for it.

The secondary osteones usually appeared earlier in the upper fragment than in the lower. A frequent observation was termination of the excavation by the cutter heads for the secondary osteones at the osteotomy line, where they widened to form the shape of an elephant's foot (Fig. 48).

This finding suggests that the osteone head was searching for a canal in the opposite fragment for its further growth on the other side. This pattern fits well with the common observation that a new secondary osteone usually grows along the old devitalized canals. The crossing of osteones from the distal fragment was observed later in the healing process, after the 8th to 10th week.



FIG. 50. - Group S Fluorescence preparation 16 weeks after nailing (L.C. 52-82-112) Osteotomy line still visible. A large secondary osteone crosses the line in the centre of the cortex. Periosteal lamellar bone deposition is going on since at least the time of the red labelling-day 82. Bottom left part of the lamellar bone cast surrounding the nail.



FIG. 54. - Group NS Spalteholz preparation 2 weeks after nailing Total avascularity of the cortex even far away from the osteotomy line on the right.



FIG 55 - Group NS Fluorescence preparation 2 weeks after nailing (L C. 6-10-14). The peripheral reaction is delayed, marked with only green labelling. Resorption scalloping in both fracture ends No bone in the gap



FIG. 52. - Group S. Fluorescence preparation 10 weeks after nailing (L.C. 46-58-70). The longitudinal remodelling of the transversally deposited bone in the gap.



FIG. 53. - Group S Fluorescence preparation 10 weeks after nailing (L C 46-58-70). Triangular shaped area of resorption and deposition This process is usually not delayed.

Group NS

The most impressive finding was the lack of vessels and bone in the gap. In Spalteholz preparations examined after the 2nd and also the 4th week, there was an almost total absence of vessels in the cortical ends (Fig. 54).

This is remarkable in comparison with the rapid revascularization observed in group S. Even after the 6th week, when some bone would appear in the osteotomy line, the osseous communication between the fragments consisted mainly of a bridging periosteal cuff.

The cortical ends always remained totally «cold» and avascular without any signs of vessels entering the cortex (Fig. 55), and very seldom cutter heads were seen there even in the 10th week. The characteristic secondary osteones so often observed during this time in group S seemed to have been replaced by the formation of large resorption intracortical cavities. At this time—the 10th week—interfragmental new bone connected the ends of the necrotic cortical bone in some cases (Figs. 56 and 37).

woven bone was formed around these vessels. This bone was later condensed by the formation of primary osteones and sometimes also by secondary osteones. These transformed the newly formed bone into mature lamellar bone disposed transversally along the gap, usually between the 3rd and 6th weeks (Fig. 51).

The bone was often firmly fixed to the borders of the gap, which was often found to be eroded by osteoclastic resorption arches (Fig. 51).

After the 3rd to 4th week, vessels from the gap sometimes, though not often, found their way into the cortical ends, forming a typical pattern, which is shown in Fig. 51. Here, as well as in the well adapted osteotomy line, secondary osteones crossed the gap after the 6th week, remodelling the bone already formed and restoring the longitudinal architecture of the diaphyseal bone (Fig. 52).

In some cases a wedge-shaped defect was found at the outer part of the osteotomy line, probably caused by the sawing and not an effect of resorption. This defect was filled at an early stage with woven bone, which was later rebuilt in the same way as the bone in the wide gap (Fig. 53).



FIG. 56 - Group NS Fluorescent preparation 16 weeks after nailing (L C 52-82-112). The cortical ends have been largely resorbed and the old bone is replaced by large cortical cavities There is, however, some interfragmentally formed bone visible at the level of the arrow and the cortical end contact is defective The periosteally formed bone is condensed to a strong reliable fragment uniting bridge (right)

DISCUSSION

Nailing has for many years been a well accepted and valuable method in the treatment of some diaphyseal fractures. Improvements of the technique, however, have been based more on clinical experience than on experimental studies.

Reaming of the medullary cavity with the use of a stronger nail has increased the number of fractures suitable for this treatment. This method has greatly improved the stability and has made immediate weight bearing possible. These are very important factors in the treatment of diaphyseal fractures. Opponents of the method often argue that this mode of treatment causes extensive damage to the circulation of the bone and, as a consequence, increases the risk of complications such as infections and delayed union. They also point out that the method may increase the swelling of the leg and cause circulatory disturbances (Nylander and Semb 1970). The opponents therefore consider that the advantages of the method do not compensate for its disadvantages.

On nailing, and especially on reaming, the medullary vessels in the diaphyseal part of the bone are destroyed. This, together with the periosteal damage caused by a fracture or by an experimental osteotomy, can result in some damage to the cortical circulation.

Previous experiments on rabbits have shown that reaming in the medullary cavity often produces a high intramedullary pressure that forces bone marrow into the intracortical canals, where it may obstruct a large part of the circulation (Danckwardt-Lillieström 1969*c*).

If, however, the reaming is performed after previous evacuation of the marrow contents and during suction of the medullary cavity, the cortical avascularity can be reduced to a very great extent (Danckwardt-Lilliestróm et al. 1970).

With the present experimental work we have tried to evaluate in what way an osteotomy, firmly stabilized with a compression nail, will heal in the presence of different degrees of cortical damage provoked by the reaming.

The « dome-shaped » osteotomy just below the level of the tibio-

In earlier experiments (Olerud et al. 1969) it was found that blood samples from the femoral vein during reaming contained numerous marrow particles.

The soft tissue reaction around the osteotomy in group S was small and of short duration in comparison with group NS, where it was sometimes very extensive and persisted for a long period.

The local clinical findings at the different observation times in the different groups corresponded with the roentgenological and microscopical patterns. The small degree of periosteal bone formation in group S was very similar to the reaction observed in experiments with intermediate avascular fragments stabilized by a compression plate in dogs (Olerud & Danckwardt-Lillieström 1970). The bone was formed almost exclusively close to the osteotomy line, and the first formed woven bone very quickly rebuilt to lamellar bone. In this group we were unable to confirm the generally accepted profuse periosteal bone formation after medullary nailing described from experimental findings by Trueta and Cavadias (1955), Andersson (1965), Richany et al. (1965), Rhinelander et al. (1967) and many others and from clinical observations by Küntscher (1962) and Böhler (1949).

In group NS where the aim was to obtain a high intramedullary pressure during reaming, the considerable soft tissue swelling corresponded to a large amount of callus all along the diaphysis. Such a periosteal reaction was found in some animals by Danckwardt-Lillieström (1969*c*) on reaming the medullary cavity of the rabbit tibia without fracture. This supports the opinion that these periosteal reactions do not depend upon instability. In spite of the considerable peripheral bone formation, clearly visible roentgenologically, the new bone did not always bridge the osteotomy line all around the bone. Some parts of the line were, however, often firmly bridged. This proves that the absence of bridging in other parts is not due to lack of stability.

Our technique with the « dome-shaped » osteotomy fixed with the compression nail assured us of complete stability of the osteotomy in both groups. Stability is considered by many authors (Yamagishi et al. 1955, Friedenberg 1952, Rhinelander et al. 1967, Küntscher 1962) to be a factor which diminishes peripheral bone formation. In our study, however, although good stability was achieved in almost all animals, the large peripheral reaction was only found in group NS. We consider, therefore, that the peripheral bone formation depends, at least under our conditions, much more on subperiosteal marrow deposition, eli-

-fibular synostosis, stabilized by a compression nail, has proved to be a suitable model.

The aim of the compression nail is to obtain such good stability that the vascular proliferation in the osteotomy area will not be mechanically disturbed. The compression itself certainly does not induce bone formation, but only maintains the stability, especially by preventing rotation. The compression forces sometimes resulted in slight deformation of the osteotomy ends, but in our opinion the deformity does not produce any disturbance of the cortical canals outside the deformed area.

In group S, since the fatty marrow had been evacuated previously, the impairment of the cortical circulation in the middle part of the diaphysis was due mainly to disruption of vascular communications between the marrow and the cortex. Another reason for the impaired cortical circulation in group NS was the subperiosteal medullo hematoma (Zucman et al. 1968, Danckwardt-Lillieström 1969*c*). This separates the periosteum and disrupts the vascular communications between the periosteum and cortex, which result in further damage to the cortical bone in this area. This medullo hematoma may have a similar effect to that of autologous bone marrow transplantation as described by Burwell (1966).

In our two main experimental groups, group S and group NS, a definite difference in pattern was observed throughout, not only as regards the cortical vascular damage, but also in the general and local clinical appearance, radiological findings and the microscopical healing pattern.

The operative procedure in itself causes stress in the organism as a whole, as has been pointed out by many authors. In spite of the fact that these rabbits were still in the age of growth, they stopped growing for a period of about 20 days This was observed in both groups. There were, however, some differences between animals undergoing the more crude operation—the non-suction group—and those in which the operation was more careful— the suction group. The former animals appeared to be more affected generally, with, on the whole, a slower weight increase, perhaps due to a larger degree of local trauma and also possibly due to an effect of the distribution into the organism of marrow particles, mobilized by the reaming in this group.

The death rate from fat emboli in the non-suction group was 11%, and a further 10% showed clear signs of the fat embolism syndrome but survived.

wo groups in the revascularization and bone formation at the fracture ine. In group S vessels already appeared in the first week, and were followed almost immediately by bone formation, so that the gap in the X-ray pictures had almost disappeared by the 4th to 5th week. A period of 4 to 6 weeks is considered normal for a rabbit tibia to heal (Varma and Metha 1967). In group NS, however, the osteotomy line remained clearly visible and with little reaction even up to the 13th and even the 16th week. The consolidation in these cases depends almost solely upon the enormous periosteal bone formation, and in spite of this bone formation a reliable union between the osteotomy ends will seldom take place. Real bone union never seems to occur between the fracture ends when the intracortical circulation is blocked by fat emboli. In group S there was also vascular invasion from the gap into the osteotomy ends. Also this phenomenon was never seen in group NS. This indicates that there must be some factor in the cortex, probably the fat in the intracortical canals, which, mechanically or chemically, may prevent the invasion of vessels. Supporting the chemical influence is the fact that vessels in group NS would sometimes not even grow into the fracture gap.

Depending upon the size of the osteotomy gap, woven bone or lamellar bone is formed. In later stages, i.e. the 6th to 8th week, the line will be crossed by secondary osteones. Small areas in the region of close contact will, however, still remain unrebuilt after a very long time—up to the 16th week. The reason for this might be that the mechanically very stable nail will eliminate space polarizing factors as a stimulus for total cortical remodelling (Frost 1963, Schenck 1965).

In group S the nail was very soon surrounded by newly formed bone, and later it was « locked » even more closely by thicker mature lamellar bone. At the same time the endosteal part of the original cortex was extensively resorbed but replaced by stable beams which connected the bone cast around the nail with the original cortex, and the nail would never loosen. The nail will in this way also give « stress protection » to the bone, which can explain the spongialization and delay in final remodelling of the cortex, which was very slow in the later stages

In group NS, where the bone healing was extremely retarded, the anchoring of the nail was very poor. This was certainly due to the impaired vascular situation. The nail had to function as a stabilizing factor for a longer period of time because of the delay in consolidation.

mination of the marrow circulation and cortical bone necrosis than on instability, though this can be a contributory factor.

The often extensive periosteal bone formation in the Bündelnagelung method (Hackethal 1961) may fit well with this opinion, since a large amount of the marrow content will be forced out from the medullary cavity by the steel pins.

The revascularization of the cortical bone which starts at an early stage from all vascularized areas of the surrounding soft tissue, the periosteum, cortex and marrow cavity, occurred in different ways in the two groups. In group S it followed two lines, firstly by connection with preexisting vessels, in the same way as described by Birch and Brånemark (1969) in revascularization of full thickness skin grafts and by Olerud and Danckwardt-Lillieström (1970) in experiments with avascular cortical fragments, and secondly by the cutter head procedure. In this respect the periosteum plays the largest role in furnishing the blood supply through the cortex to the vascular front. The original centrifugal flow in the cortex furnished by the nutrient artery will be replaced by a centripetal flow from the periosteal vessels. Such a conversion of blood flow has been described by many authors (Brookes 1960, Rhinelander and Bargary 1962, Cavadias and Trueta 1965, Ladanyi et al. 1965) from studies with different experimental models. By vessels perforating the cortex and via vessels passing through the fracture line and by a contribution from the metaphyseal systems, the endosteal circulation will be partly restored.

Revascularization of the large avascular areas of cortex in group NS seemed to be very difficult. Central to the sparsely vascularized outer part of the cortex, cystic cavities were formed which later enlarged and became confluent. The cavities were furnished from vessels increasing in size through the outer cortex. The cortex central to the cavities was not invaded by vessels, but only eroded from the surface. This may have been due to blockage of the bone canals by fat. The decomposed fat may act as a toxic factor and prevent normal revascularization. After some time parts of the inner cortex became sequestrated and at least partly resolved, and this can be seen in the X-ray pictures. The cortical damage in this group showed wide interindividual variations and as a consequence of the conditions described above there were important quantitative differences. The endosteal revascularization also exhibited great variety in timing and intensity.

The osteotomy ends in both groups, S and NS, were primarily avascular. In spite of this, definite differences were seen between the

two groups in the revascularization and bone formation at the fracture line. In group S vessels already appeared in the first week, and were followed almost immediately by bone formation, so that the gap in the X-ray pictures had almost disappeared by the 4th to 5th week. A period of 4 to 6 weeks is considered normal for a rabbit tibia to heal (Varma and Metha 1967). In group NS, however, the osteotomy line remained clearly visible and with little reaction even up to the 13th and even the 16th week. The consolidation in these cases depends almost solely upon the enormous periosteal bone formation, and in spite of this bone formation a reliable union between the osteotomy ends will seldom take place. Real bone union never seems to occur between the fracture ends when the intracortical circulation is blocked by fat emboli. In group S there was also vascular invasion from the gap into the osteotomy ends. Also this phenomenon was never seen in group NS. This indicates that there must be some factor in the cortex, probably the fat in the intracortical canals, which, mechanically or chemically, may prevent the invasion of vessels. Supporting the chemical influence is the fact that vessels in group NS would sometimes not even grow into the fracture gap.

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In group NS, where the bone healing was extremely retarded, the anchoring of the nail was very poor. This was certainly due to the impaired vascular situation. The nail had to function as a stabilizing factor for a longer period of time because of the delay in consolidation.

The resorption around the nail will win over the bone formation, with instability as a result. The pseudarthrosis in our rabbits may have been due to this reason. Probably in some cases the cause of delayed healing and pseudarthrosis occurring in clinical practice (L. Böhler 1953, Bürkle de la Camp 1958) can be referred to these factors.

CONCLUSIONS

This experimental work aimed at answering some fundamental questions in the treatment of fractures with reaming and nailing. Though this type of surgery has many aspects, and many problems still remain untouched, we believe that the questions we posed in the introduction can be given some answers:

To the cortical damage, produced by reaming of the medullary cavity the osteotomy adds total avascularity of the osteotomy ends. The nail itself does not seem to produce any further damage to the cortical circulation.

When the avascularity is due to severance of the vascular communication the revascularization process is rapid and occurs by connection with preexisting intracortical vessels or by cutter head formation. The latter process is more or less complete and takes place without any major cyst formation in the cortex. If the avascularity is due to fat emboli in the intracortical canals, the revascularization is very slow and incomplete. Large cystic cavities are formed, which become confluent and often sequestrate parts of the inner layer of the cortex.

With minor cortical damage under stable conditions, limited periosteal bone formation almost invisible on X-ray pictures is seen. With a larger extent of cortical damage, even under stable conditions, considerable periosteal bone formation creates a new cortex.

Under stable conditions and with minor cortical damage, the repair is characterized by immediate bone formation in the osteotomy gap (if such exists), followed by remodelling of the cortex and fracture area by secondary longitudinal osteones. The nail itself, fully fitting the fracture region in the medullary cavity, does not in any way impair the bone formation and healing of the osteotomy because of the good vascularity supplied in the early stages mainly from the periosteal vascular system.

With extensive cortical damage due to marrow emboli, the healing of the osteotomy line is very slow and incomplete or may fail owing to impaired revascularization of the osteotomy ends and the

pronounced resorption in this region. If consolidation of the fracture occurs, this will rely on the condensed periosteal bone which acts as a stabilizing cuff around the diaphysis at the osteotomy level.

In the former case, with less cortical damage, the nail will be enclosed firmly, at the same time as bone is laid down in the osteotomy gap. Under the second condition, when large cortical damage is present this enclosing process is greatly delayed. Resorption forces are more pronounced and there is a serious risk that the nail will became loose before the circumferential repair is strong enough to maintain the stability. Instability may then often result in pseudarthrosis.

BIBLIOGRAPHY

ANDERSON L. D. - GILMAR W. S J. - TOOMS R E. (1962): *Experimental fractures treated with loose and tight fitting medullary nails.* Surgical Forum, *13*, 455.

ANDERSON L. D (1965). *Compression plate fixation and the effect of different types of internal fixation on fracture healing.* J. Bone Jt. Surg, *47/A*, 191.

BACKER-GRØNDAHL N. B. (1911): *Untersuchungen über Fettembolie.* Deutsch Z. Chir., *111*, 56

BAGBY G W. - JAMES J. M. (1958): *The effect of compression on the rate of fracture healing using a special plate.* Am. J. Surg., *95*, 761.

BERGENTZ S. E. (1961) *Studies on the genesis of posttraumatic fat embolis.* Acta Chir. Scand Suppl 282.

BIRCH J - BRÅNEMARK P.-I (1969): *The vascularization of a free full thickness skin graft. I A Vital Microscopic Study.* Scand. J. Plast Reconstr. Surg, *3*, 1-10.

BÖHLER J (1968): *Closed intramedullary nailing of the femur.* Clin Orthop, *60*, 51

BOHLER L (1953): *Unterschenkelschaftbrüche* Arch. Klin Chir, *276*, 192.

BOHLER L. - BÖHLER J (1949). *Küntscher's medullary nailing.* J. Bone Jt. Surg, *31/A*, 295

BROOKES M. (1960) *The vascular reaction of tubular bone to ischaemia in peripheral occlusive vascular disease.* J. Bone Jt. Surg, *42/A*, 110.

BROOKES M. - HARRISON R. G (1957): *The vascularization of the rabbit femur and tibiofibula* J. Anat, *91*, 61

BÜRKLE DE LA CAMP H. (1958) *Fehler und gefahren der alloplastik in der knochen und gelenkchirurgie.* Arch Klin. Chir, 289, 463.

BURWELL R G (1966) *Studies in the transplantation of bone.* J. Bone Jt. Surg, *48/B*, 532-566

CAVADIAS A X. - TRUETA J (1965). *An experimental study of the vascular contribution to the callus of fracture.* Surg Gyn Obst, *120*, 731.

DANCKWARDT-LILLIESTRÖM G (1967). *Periostal reaktion vid märgborrning å kanin* Nord Med., *77*, 59.

DANCKWARDT-LILLIESTRÖM G. (1969*a*). *Fettembolier till rörbenets cortex.* Nord Med, *81*, 479

DANCKWARDT-LILLIESTROM G (1969*b*)· *Marrow embolism as a cause of circulation block after surgery to the medullary cavity.* Europ. Surg Res, *1/3*, 174

DANCKWARDT-LILLIESTRÖM G (1969*c*) *Reaming of the Medullary Cavity and Its Effect on Diaphyseal Bone* Acta Orthop. Scand Suppl., 128

DANCKWARDT-LILLIESTRÖM G. - LORENZI G. L. - OLERUD S (1970): *Intracortical circulation after intramedullary reaming with reduction of pressure in the medullary cavity.* J Bone Jt. Surg. (in press)

DANIS R. (1949): *Théorie et pratique de l'ostéosynthèse.* Masson et Cie ed, Parigi

DE MARNEFFE R. (1951): *Recherches morphologiques et expérimentales sur la vascularization osseuse.* Acta Chir. Belg., *50*, 469/568/681.

DE MARNEFFE R. (1953): *Les connaissances actuelles de la vascularization des os et leur incidence sur la pathologie de ce tissu.* Rev. rheum. et maladies ostéo-artic., *20*, 113.

FITZGERALD F. P. (1966): *A new intramedullary nail for nonunion.* Intern. Surgery, *45*, 414.

FRIEDEBERG Z. B. - FRENCH G. (1952): *The effects of known compression forces on fracture healing.* Surg. Gyn. Obst., *94*, 743.

FROST H. M. (1963): *Bone remodelling dynamics.* C. Thomas ed., Springfield.

GEISER M. (1963): *Beitrage zur biologie der Knochenbrücheilung.* F. Enke Ed, Stuttgart.

GÖTHMAN L. (1960*a*): *The arterial pattern of the rabbit's tibia after the application of an intramedullary nail.* Acta Chir. Scand., *120*, 211.

GÖTHMAN L. (1960*b*): *Arterial changes in experimental fractures of the rabbit's tibia treated with intradullary nailing. A Microangiographic study.* Acta Chir. Scand., *120*, 289.

GÖTHMAN L. (1961): *Vascular reactions in experimental fractures.* Acta Chir. Scand. Suppl., 284.

GRANT R. T. - REEVE E B (1951): *Observations on the General Effects of Injury in Man.* Medical Research Council. Special Report Series 277. His Majesty's Stationary Office, London

GRIESSMANN, R. (1944): *Vergleichende Untersuchungen über den Ablauf den Knochenbruchheilung.* Arch. klin. Chir., *205*, 3.

GUSTILO B. R. - NELSON G. E. - HAMEL A. - MOE J. H (1964): *The effect of intramedullary nailing on the blood supply of the diaphysis of long bones in mature dogs.* J. Bone Jt. Surg., *46/A*, 1362.

HACKETHAL K. H. (1961): *Die Bündel-Nagelung. Experimentelle und Klinische Studie über eine neuartige Methode der Markraum-Schienung langer Rohrenknochen.* Leitfaden der Technik, Springer-Verlag.

HEY GROVES E. W. (1918): *Ununited fractures with special reference to gunshot injuries and the use of bone grafting* Brit Jour Surg., *6*, 203

JOHNSON L C. (1966): *The kinetics of skeletal remodelling.* In: « *Structural organisation of the skeleton* ». D Begsma Ed, New York

KAESSMANN H. J. (1966) *Stabile Osteosynthese durch den Kompression snagel.* Chirurg., *37*, 272.

KAESSMANN H. J. - WEBER H G (1969) *Der Kompressionsnagel, eine modifikation des marknagels nach Kuntscher* Brun's Beitrage zur Klin Chir, *217*, 315.

KERSTELL J. (1969) *Studies on the pathogenesis of post-traumatic fat embolism* Acta Med Scand Suppl, *499*, 1969

KOEKEMBERG L J. (1963): *Vascularisation in the healing of fractures* Chirurgische Universiteits Kliniek, Ed, Amsterdam

KÜNTSCHER G (1940*a*): *Ein neues frakturheilverfahre* Klin Wschr, *19*, 335

KUNTSCHER G. (1940*b*) *Die marknagelung von Knochenbrüchen* Klinischer Teil, Klin. Wschr., *19*, 833.

KUNTSCHER G (1941): *Callus ohne knochenbruch.* Ztbl fur Chirurg, *68*, 857

KUNTSCHER G. (1950): *Die Marknagelun* Saenger Edit., Berlin

Küntscher G (1958): *The Küntscher method of intramedullary nailing*. J. Bone Jt. Surg, *40/A*, 17.
Küntscher G. (1962): *Praxis der Marknagelung*. Friedrich-Karl Schattauer-Verlag, Stuttgart.
Ladanyi J. - Foldes I. - Tasnady L. (1965): *Blood supply of the callus after intramedullary nailing*. Acta Chir. Hung, *6*, 365.
Lambotte A (1913): *Chirurgie Opératoire des fractures*. Masson Ed, Parigi.
Landelius E. (1951): *Intramedullary Pinning with Kirschner Wires*. Acta Chir. Scand, *101*, 203.
Lange M (1954): *Il trattamento chirurgico e la osteosintesi metallica nelle fratture*. Arch Putti, *5*, 45.
Lechner F. - Schuster J. (1963): *Sur le traitment dirigé de l'embolie graisseuse par le phospholipides «essentiels» (substance EPL)*. Chir. Praxis, *7*, 13.
Lehman E. P. - McNattin R. F. (1928): *Fat embolism; incidence at postmortem*. AMA Arch Surg, *17*, 179.
Maatz R. (1951): *Die wundmechanik in der federosteosynthese*. Ztschr. Orthop, *80*, 643
Mital M - Cohen J. (1966). *Repair of experimental bony intramedullary injuries varying in degree* Surgical Forum, *17*, 451.
Mörl F K. (1967) *Embolia grassosa ed inibitori delle proteasi*. Die Med. Welt, *35*, 9.
Nylander G - Semb H (1970) *The veins of the lower leg after tibial fractures*. Surg Gyn. & Obstr (in press)
Olerud S - Danckwardt-Lilliestrom G. (1968): *Fracture healing in compression osteosynthesis in the dog*. J. Bone Jt. Surg, *50/B*, 844.
Olerud S - Danckwardt-Lilliestrom G. (1970): *Fracture healing in compression osteosynthesis An experimental study in dogs with an avascular, diaphyseal, intermediate fragment*. Congress band 1970. SICOT.
Olerud S - Danckwardt-Lillieström G - Lorenzi G. L. (1969): *Do medullary components appear in the femoral vein during the reaming of the tibia?* Europ. Surg Res, *1/3*, 243
Olerud S - Lorenzi G L. (1969) *Triple fluorochrome labelling of the bone*. Europ Surg Res, *1/3*, 177
Olerud S - Lorenzi G L. (1970): *Triple fluorochrome labelling in bone formation and bone resorption* J Bone Jt Surg *52/A*, 274
Palmer J (1951) *On the complications and technical problems of medullary nailing*. Acta Chir Scand, *101*, 484
Peltier L F (1956) *Fat embolism The prophylactic value of tourniquet*. J. Bone Jt Surg, *38/A*, 835
Peltier L F (1956) *Fat embolism III. The toxic properties of neutral fat and free fatty acids*. Surgery, *40*, 665
Petrokov V (1962) Bruns Beitr. klin Chir., *205*, 265.
Rhinelander F W (1968) *The normal microcirculation of diaphyseal cortex and its response to fracture*. J. Bone Jt Surg, *50/A*, 784.
Rhinelander F W - Bargary R. A (1962): *Microangiography in bone healing. I undisplaced closed fractures*. J Bone Jt. Surg, *44/A*, 1273.
Rhinelander F W - Gracille R. - Phillip R. - Steel W. (1967): *Micrangio-*

graphy in bone healing. III: Osteotomies with internal fixation. J. Bone Jt. Surg., *49/A*, 1006.
RICHANY S. F. - SPINZ H. - KRANER K. - ASHBY J. - MERRIL J. G. (1965): *The role of the diaphyseal medulla in the repair and regeneration of the femoral shaft in the adult cat.* J. Bone Jt. Surg., *47/A*, 1565.
ROKKANEN P. - SLÄTIS P. - VONKKE E. (1969): *Closed or open intramedullary nailing of femoral shaft fractures.* J. Bone Jt. Surg., *51/B*, 313.
RUSH L. V. - RUSH H. L. (1937): *A reconstruction operation for comminuted fracture of the upper third of the ulna.* Amer. J. Surg., *38*, 332.
RUSH L. V. - RUSH H. L. (1949): *Evaluation of Medullary Fixation of Fractures by the Longitudinal Pin.* American J. of Surg., *3*, 324.
SALDEEN T. (1969): *Intravascular coagulation in the lungs in experimental fat embolism.* Acta Chir. Scand., *135*, 653-662.
SCHENK R. (1965): *Primary healing of fractures.* The Roche Courier, *18*, 23.
SCHENK R. - WILLENEGGER H. (1963): *Zum histologischem bild der sogenannten primärheilung der knochenkompakta nach experimentellen Osteotomien am Hund.* Experientia, *20*, 593.
SCHENK R. (1965): *Fluoreszenmikroskopische untersuchungen zur heilung von Schaftfrakturen nach stabiler Osteosynthese am Hund.* Proc. 2nd Europ. Symp. on Calc. Tissues, pag. 125.
SCHENK R. - WILLENEGGER H. (1967): *Morphological findings in primary fracture healing.* Symp. Biol. Hung., *7*, 75.
SCHNEIDER H. W. (1968): *Use of the 4-flanged self-cutting intramedullary nail for fixation of femoral fractures.* Clin. Orthop., *60*, 29.
SILANI C. - AMANTE S. (1949): *Ricerche sperimentali sul trattamento delle fratture secondo Küntscher.* Arch. Ortop., *62*, 165.
SPALTEHOLZ W. (1911): *A method for clearing of human and animal specimens* Verlag von S. Hirzel ed., Leipzig.
TRUETA J. - CAVADIAS A. X. (1955): *Vascular changes caused by Küntscher type of nailing.* J. Bone Jt. Surg., *37/B*, 492.
TRUETA J. - CAVADIAS A. X. (1964): *A study of blood supply of the long bone.* Surg. Gyn. Obst., *118/3*, 485.
UFFREDUZZI O. (1942): *Fissazione dei monconi di frattura con chiodi midollari lunghi e sottili.* Giorn. Accad. Med., Torino, pag. 7.
VARMA B. P. - METHA S. H. (1967): *Fracture healing with intramedullary nail fixation of the long bones. An experimental study.* Acta Orthop. Scand., *38*, 419.
WEHNER W. (1968): *Die Fettembolie VEB.* Verlag Volk und Gesundheit, Berlin.
VESELEY D. G. (1968): *Technic for use of the single and the double split diamont nail for fractures of the femur* Clin. Orthop., *60*, 95.
VINDITTI D. - BENINI M. (1962): *Proposta di un chiodo endomidollare a pressione o coartante.* Min Ort., *13*, 368
YAMAGISHI M. - YOSHIMURA Y. (1955). *The biomechanics of fracture healing.* J. Bone Jt. Surg., *37/A*, 1035.
ZUCMAN J. - MAURER P - BERBESSON C. - BARBOT J (1968) *Etude expérimentale de l'action ostéogenique des greffes de périoste, des greffes de moelle osseuse et de l'alesage centro-médullaire.* Revue de Chir. Orthop., *54*, 15

AULO GAGGI EDITORE BOLOGNA

HELGE APPEL

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ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO. 133
MUNKSGAARD COPENHAGEN 1970

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From the Department of Orthopaedic Surgery (Head Prof. J. Sevastikoglou, M D), University Hospital, Umeå, Sweden, and the Department of Orthopaedic Surgery (Head Prof R Magnusson, M D), Regional Hospital, Linköping, Sweden.

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BY

HELGE APPEL

MUNKSGAARD
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by

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CHAPTER I

Introduction

Articular injuries, including operative procedures, are generally regarded as influencing the occurrence of degenerative arthritis of the affected joint. The connection between intra-articular procedures and secondary degenerative arthritis can hardly be denied, but this experience is almost exclusively based on clinical empiricism and not on concrete facts.

Ruptures of the semilunar cartilage of the knee are the most common intra-articular injuries and consequently, their removal is the most usual intra-articular procedure. The relation between removal of the semilunar cartilage of the knee and the development of degenerative arthritic changes in the joint is a controversial subject. This applies to both the frequency of occurrence of degenerative arthritis following the operative procedure and the effect of different factors, — such as trauma, duration of the preoperative history, age at the time of operation, — on the development of degenerative arthritis.

A number of follow-up examinations of, and reports on, patients who had been subjected to meniscectomy, showed clear-cut results with regard to the occurrence of degenerative arthritis after removal of the semilunar cartilage of the knee. However, the frequency rates stated by various authors and the importance they attach to the different factors in the development of degenerative arthritis vary very widely. As a rule the results reported are based on the authors' own material, where, to a *certain extent, subjective* evaluation cannot be entirely excluded; the results are also often based on small series and on the analysis of only one or of a few factors which are regarded as playing a role in the development of secondary changes in the joint. Furthermore, only a few authors confirm their results on the basis of statistical analysis.

Authors who recommend partial resection of an injured semilunar cartilage, consider that its total extirpation changes the statics and dyna-

mics of the operated knee to such a high degree that the late results are less satisfactory than after partial resection (Dengler 1938, Weisbach 1942, Hübner 1943, L. Böhler 1955, Krömer 1955, Streli 1955, Jonasch 1964). The advocates of total meniscectomy consider on the other hand that the "regenerate" after partial resection is qualitatively and functionally worse than after total extirpation. There is, therefore, a greater risk of a new rupture and of degenerative arthritis after partial resection than after total meniscectomy (Bürkle de la Camp 1936, Andreesen 1937, Magnus 1938, Mandl 1940, Schaefer 1953, Frosch 1956, Smillie 1962, Schilling 1963 and 1965, Strelec & Wozelka 1964, Zippel 1964, Herschmann 1965, Jelinek 1965, Springorum 1966).

There are also authors who state that one has to decide from case to case the type of operation to be performed (Hagemeyer 1955, Leuschner & Weickert 1964, Tapper & Hoover 1969).

Access to a large number of patients, who had been subjected to meniscectomy during almost half a century, and personal follow-up examination of the majority of the cases have made it possible to analyze objectively the results obtained, with long observation periods. The size of the material has further made it possible to treat statistically the obtained results with consideration of different factors which might influence the occurrence of degenerative arthritis. For these reasons a detailed report on this material was considered well justified in order to meet the need for concrete and clear-cut answers to the following main questions:

— to what extent is the operated knee affected by roentgenological signs of degenerative arthritis compared with the nonoperated joint;
  and if there are any differences in the occurrence of degenerative arthritis are these significant?
— to what extent have the patients subjective discomfort and objective symptoms after removal of the semilunar cartilage of the knee?
— which factors could possibly influence the fate of the meniscectomized knee?
— is partial resection or total extirpation to be preferred when choosing the method of operation?

CHAPTER II

Material

The basic material comprised all the patients who, during the period 1921—1960, were operated at the Regional Hospital in Linköping, Sweden, for rupture of the semilunar cartilage of the knee, in all 718 persons. Fig. 1 shows the number of operations during the different 10-year periods. Up to 1950 these patients were operated at the Department of General Surgery, but since the autumn of 1950 all injuries of the semilunar cartilage were operated on at the Department of Orthopaedic Surgery. Examination of the patients was performed during 1965 and the first half of 1966, by the author himself. Therefore, only patients who were resident in the reception area of the Regional Hospital in Linkoping at the time of the follow-up could be included in this investigation. No selection was made of the material investigated.

The method adopted when trying to trace the patients was based partly on the county register and partly on inquiries to the parish registrar's offices. No information could be obtained regarding 49 persons. Seven patients were resident abroad. The parish registrar's offices furnished information on 42 deceased patients. Seventeen of these had been operated during the period 1921—1940 and 25 during the period 1941—1960. Moreover, 123 patients were traced, who at the time of the follow-up examination were living outside the reception area of the Regional Hospital in Linkoping. In all, 497 persons were found who could be considered for follow-up investigation. On receiving an invitation 480 of them answered by attending for a follow-up examination. This represents 66.8 per cent of the total number of operated patients and 96.5 per cent of those who were known to be living in the reception area.

Table 1 shows the number of persons from the entire material who were investigated, as well as the distribution of total or partial meniscectomies and so-called "double-operations", i.e. cases where more than

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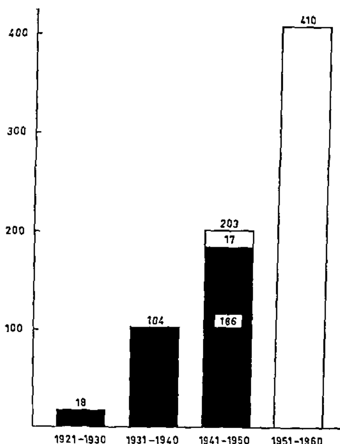


FIG. 1 Total number of meniscectomies performed at the Regional Hospital in Linköping, Sweden during the years 1921—1960.
Black columns: Operations performed in the Department of General Surgery.
White columns: Operations performed in the Department of Orthopaedic Surgery

TABLE 1. *The distribution of the whole material Patients available and those not available for follow-up examination are included M = males, F = females. % = M + F*

Patients	Total number		%	Total meniscectomy		Partial		"Double-operated"	
	M	F		M	F	M	F	M	F
Followed-up	422	58	66 8	384	56	19	2	19	0
Not ,,	212	26	33 2	198	25	8	0	6	1
Total	634	84	100 0	582	81	27	2	25	1

one semilunar cartilage was operated on in the same patient. In 6 cases among the "double-operated" both semilunar cartilages in the same knee were removed. In 13 patients one semilunar cartilage had been operated on in both knees. In the remaining 461 patients only one semilunar cartilage had been operated on. Twenty-one patients underwent partial resection and 440 total exstirpation of the meniscus. It is these last-mentioned 440 patients who underwent total meniscectomy that will be reported on as the main material in what follows. Furthermore, a brief account will be given of the patients subjected to partial resection and those who underwent a "double-operation". Very shortly, the problem of re-operation on the same semilunar cartilage will also be dealt with.

Comments on the material

Previous reports on large materials, as for instance Zippel's series (1964), with 1,360 operated patients, usually give data only on sex and age distribution as well as, among other information, the side of the semilunar cartilage operated on, but they are not based on a follow-up examination. In table 2 follow-up investigations reported by different authors are summarized. Some of these follow-ups are based wholly or partially on questionnaires sent to the patients, and are thus, a report only on the patient's conception of his complaint. With regard to the number of re-examined persons, the present material is comparable with other followed-up series.

TABLE 2 *Materials, period of observation and method of judging the results, according to different authors*

Authors	Number of cases	Followed up	Time of observation	Remarks
Strahlman & White (1921)	*	50	*	All by questionary
Birgfeld (1928)	85	59	*	*
Raess (1930)	27	25	1—7 years	Some by questionary
Key & Strömberg (1930)	48	44	2—16 "	All personally
Frising (1930)	36	35	—9 "	Some by questionary
MacAusland (1931)	388	287	—25 "	All by questionary
Spitz (1933)	82	76	*	Some by questionary
Andersson (1934)	28	23	1—14 "	All personally
Aleman & Friberg (1934)	186	176	*	Some by questionary
Dengler (1938)	122	74	—11 "	" " "

*) No information available

Table 2 (continued)

Authors	Number of cases	Followed up	Time of observation	Remarks
Efskind (1939)	33	32	1—14 years	All personally
Uebermuth (1941)	92	55	3—15 „	„ „
Brechling (1942)	57	45	1—15 „	„ „
Sjövall (1942)	144	143	3—12 „	All by questionary
Hübner (1943)	*	35	1—15 „	All personally
Nitter (1946)	42	35	1—19 „	„ „
Fairbank (1948)	*	107	1/4—14 „	„ „
Fuss (1951)	279	100	2—16 „	„ „
Lagergren (1953)	120	97	2—25 „	Some by questionary
Aarstrand (1954)	56	48	*	„ „ „
Streli (1955)	111	82	18—25 „	All personally
Barfod & Bierring (1956)	112	110	1—18 „	„ „
Rothascher (1960)	404	353	8—14 „	„ „
Scheibe (1963)	*	127	2—12 „	Some by questionary
Saugmann-Jensen (1963)	*	351	½— 4 „	
Saugmann-Jensen (1963)	*	73	10—15 „	
Leuschner & Weickert (1964)	148	91	3—10 „	All personally
Kühnel (1964)	452	326	*	Some personally
Monn (1964)	60	52	2—17 „	All by questionary
Allegreni & Dell 'Orto (1965)	*	92	3—11 „	All personally
Huckell (1965)	462	134	11—21 „	Some by questionary
Herschmann (1965)	*	163	2—12 „	All personally
Barta & Perjés (1965)	94	71	½— „	„ „
Springorum (1966)	*	150	18—35 „	„ „
Franke (1966)	*	98	½— 5 „	„ „
Mohing (1966)	*	110	—30 „	*
Gear (1967)	150	40	10— „	Some by questionary
Jackson (1968)	640	577	4—40 „	All personally
Tapper & Hoover (1969)	*	*213*	*Average 18,9*	*Some by questionary*
Appel (1970)	718	480	4—41 years	All personally

*) No information available

1. AGE DISTRIBUTION

This refers to the age of the patients at the time of operation. Fig. 2 and 3 show the age distribution both for the entire material comprising 718 persons and for all the 480 patients who were followed up. For the "double-operated" the age at the time of the first operation is given. The mean age for the entire material was 31.9 ± 0.46 years, and for the patients who were followed-up 33.5 ± 0.53 years. Thus there was no appreciable difference in age distribution between the entire material and the patients who were followed-up.

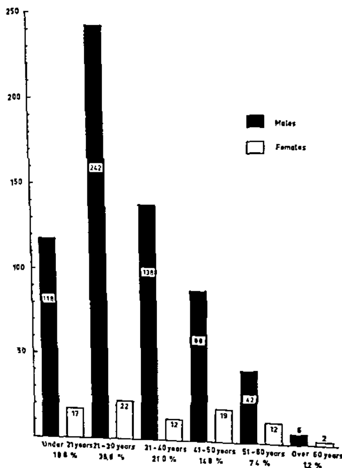


FIG 2 Age distribution of the total number of meniscectomies

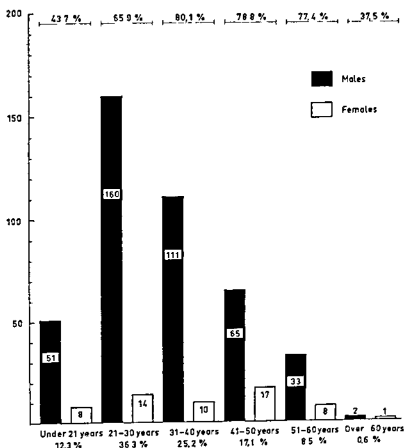


FIG. 3 Age distribution of the follow-up cases Percentages at the top refer to the relation between the followed-up patients and the total number of patients belonging to each 10-year period

Comments

The age distribution in the material of some authors is shown in table 3. It will be observed that most authors have a peak in their material during the third decade, which agrees with the condition in the present series. The mean ages stated correspond also with those given in this material. The comparatively low percentage of followed-up persons younger than 20 years at the time of the operation is probably due to the fact that in the entire material a large number of military servicemen were included, who at the time of the investigation were living outside the reception area.

TABLE 3 *Age distribution at operation, according to different authors*

Authors		Ave-rage age	Under 21 %	years 21 - 30 %	31 - 40 %	41 - 50 %	51 - 60 %	Over 60 %
Key & Strömberg (1930)	48		29 2	35 4	22 9	12.5	0	0
MacAusland (1931)	349		23 8	32 1	17 8	14 0	10 0	2.3
Spira (1933)	82		12.2	48 9	26 8	10 9	1 2	
Rostock & Runge (1937)	238	28 8	21.4	44.4	19.3	9 7	5 2	
Sjövall (1942)	144	29 3	22 9	41 0	21.5	9 7	4.9	0
Brechling (1942)	57		14 0	42 1	29 8	10.5	3 5	
Nitter (1946)	35		17.1	54.3	17.1	8 6	2 9	0
Lagergren (1953)	97		16 5	43 3	18 6	16 5	4 1	1.0
Aarstrand (1954)	56		28 6	37.5	25 0	5 4	3 5	0
Strelı (1955)	82		6 1	46 3	34 2	13.4	0	0
Barfod & Bierring (1946)	108		17 6	38 9	22 2	14 8	5 6	0.9
Scheibe (1963)	127		12 6	42.5	15 7	21.3	7.9	0
Kühnel (1964)	452		9 8	52 9	20 6	11.7	4 5	0 4
Monn (1964)	52		34 6		30 8	34 6		
Zippel (1964)	1360		18 8	49 6	17.1	9.3	5.1	0.1
Barta & Perjés (1965)	94		9 6	47.9	27 6	9 6	5 3	
Herschmann (1965)	165		16 3	32.7	21.2	15 1	12.1	2 6
Mohing (1966)	110		6 5	53 6	23 6	15 4	0 9	0
Springorum (1966)	150		90 per cent between 29—39 years					
Jackson (1968)	577		8 0	25 0	29 0	25 0	11.0	2.0
Hubner (1943)	35	30						
Huckell (1965)	134	30						
Tapper & Hoover (1969)	213	32						

2. SEX

As shown in table 1 the entire material consisted of 84 women and 634 men, giving a ratio of females to males of 1 : 7.54. Among the followed-up persons 58 were women and 422 men, and here the ratio women to men was 1 : 7.27.

Comments

In other series the ratio females to males varied widely, as demonstrated in table 4. It is difficult to find any explanation for this. The ratio reported in many other materials corresponds with the ratio in the present series.

TABLE 4. *Ratio females to males according to different authors.*

Authors	Ratio	Authors	Ratio
Frising (1930)	1:3.5	Aarstrand (1954)	1:7
Key & Strömberg (1930)	1:7	Sevastikoglou (1954)	1:7.7
MacAusland (1931)	1:1.85	Scheibe (1963)	1:3.1
Abrahamsen (1933)	1:1.3	Strelec & Wozelka (1963)	1:3 9
Andersson (1934)	1:22	Kuhnel (1964)	1:9.76
Rostock & Runge (1937)	1:2	Zippel (1964)	1:5 5
Efskind (1939)	1:1.2	Day (1966)	1:5.1
Brechling (1942)	1:4	Jackson (1968)	1:8.4
Sjövall (1942)	1:5	Tapper & Hoover (1969)	1:4

3. OPERATED MENISCUS

Among the 718 patients who were operated on in the entire material, 607 underwent medial and 137 lateral meniscectomy, which represents a ratio lateral to medial 1 : 4.43. Among the 480 persons who were followed-up 417 had had medial and 82 lateral meniscectomy, or lateral to medial 1 : 5.08.

Comments

Table 5 shows a wide variation as to the ratio lateral to medial meniscectomies in different materials with higher frequency of medial. No explanation for these variations could be advanced. Hashimoto (1958) reported a higher incidence of lateral than medial and he explains this

divergent relation in the Japanese by their manner of living. The relation in the present material, however, is in good agreement with most of the other reports.

TABLE 5. *Ratio lateral to medial according to different authors*

Authors	Ratio	Authors	Ratio
Frising (1930)	1·6 2	Hashimoto & al. (1958)	3.2.1
Key & Strömberg (1930)	1:15	Wynn Parry & al (1958)	1·2 2
MacAusland (1931)	1·3 8	Scheibe (1963)	1:13 6
Abrahamsen (1933)	1.7	Strelec & Wozelka (1963)	1:7
Andersson (1934)	0 23	Kühnel (1964)	1·10 9
Aleman & Friberg (1934)	1·6.1	Zippel (1964)	1:3 8
Efskind (1939)	1:5	Leuschner & Weickert (1964)	1:4
Brechling (1942)	1·8 5	Herschmann (1965)	1·5
Sjovall (1942)	1·3 5	Barta & Perjés (1965)	1:14
Aarstrand (1954)	1 4 7	Day (1966)	1:3 3
Streli (1955)	1:7 1	Ritchie (1966) children	1:2 9
Barfod & Bierring (1956) males	1·5	Jackson (1968)	1·3 7
females	1 2	Tapper & Hoover (1969)	1 5 1

4. SIDE

In the entire material the ratio left to right knee was 1 : 1.20 and among the persons followed-up 1 : 1.26.

Comments

No large differences between left and right operated knee were found in the material of other authors (table 6). Also in the present material both knees were affected to almost the same extent by injuries of the semilunar cartilage

TABLE 6 *Ratio left to right according to different authors*

Authors	Ratio	Authors	Ratio
Sjovall (1942)	1 1 38	Wynn Parry & al (1958)	1.1.2
Fuss (1951)	1 09 1	Zippel (1964)	1·1 13
Streli (1955)	1.1 13	Day (1966)	2·1

5. TRAUMA

Rupture of the semilunar cartilage may occur without the injured person being able to state any definite trauma. It has, therefore, been assumed that nontraumatic ruptures are due to a high degree to degenerative changes in the semilunar cartilage. In this material it was found that the injury of the semilunar cartilage was clearly associated with trauma in 80 per cent of the cases both in the entire material and in the subjects who were followed-up. Information on several traumata in the same patient has not been specially noted, despite the fact that in a number of cases several injuries were mentioned. In athletes, on the other hand, there may have been information on only one injury, although it is known that, repeated traumata of the knees are usual, e. g. in footballers.

Comments

The frequency of traumatic ruptures of the semilunar cartilage reported earlier (table 7) and that reported in the present investigation were about the same.

TABLE 7. *Percentage traumatic ruptures of the semilunar cartilage according to different authors*

Authors	Per cent	Authors	Per cent
Key & Stromberg (1930)	93 7	Barfod & Bierring (1956)	85 7
Brechling (1942)	75 0	Scheibe (1963)	77 9
Sjovall (1942)	91 6	Barta & Perjés (1965)	79.8
Nitter (1946)	97 6	McLaughlin (1966)	92.8
Aarstrand (1954)	73 2		

6. INJURIES IN ATHLETES

Twenty-eight per cent of all operated patients related the rupture of the semilunar cartilage directly to injury occurring in the course of athletics. The majority of these patients were men.

Comments

Other authors had an appreciably higher percentage of injuries connected with athletics (table 8) than that shown in this material. The number of patients stated in another Swedish investigation (Sjovall, 1942) agrees

best with the percentage for the present material. It is difficult to decide, however, whether this is due to special Swedish conditions or to a certain selection in the material of other authors. One explanation of the differences may be, that other authors have apparently calculated the percentage of injuries occurring in the course of athletics on the basis of meniscectomies performed on patients with a clear trauma in the history and not, as in this material, as a percentage of the entire number of cases.

TABLE 8 *Frequency of lesions of the semilunar cartilage due to sport trauma according to different authors*

Authors	Per cent	Authors	Per cent
Raess (1930)	60.7	Aarstrand (1954)	48 2
Spira (1933)	50 0	Bestle (1955)	40 5
Rostock & Runge (1937)	47 1	Wynn Parry & al (1958)	69 0
Sjovall (1942)	33 0	Zippel (1964)	58 8
Nitter (1946)	57 1		

7. LATENCY PERIOD

The time that elapsed between the injury or the first appearance of the symptoms respectively and the time of operation — termed in this investigation the latency period — is shown in table 9 with regard to the number of cases in each time group. If data on several injuries were available

TABLE 9 *Distribution of the whole material and the followed-up cases with regard to the latency period M = males, F = females % = M + F.*

Latency period	Number of cases M	Number of cases F	%	Followed-up M	Followed-up F	%
1 week	59	4	8 6	37	3	8 1
8—14 days	27	3	4 1	14	1	3 1
15 days—1 month	60	7	9 1	42	3	9.1
Total within 1 month	146	14	21 8	93	7	20 3
1—6 months	208	34	32 9	138	24	32.9
Over 6 months	296	37	45 3	203	27	46 8
Total	650	85 [1]		434	58 [2]	

[1]) 17 cases operated on twice
[2]) 12 „ „ „ „

5. TRAUMA

Rupture of the semilunar cartilage may occur without the injured person being able to state any definite trauma. It has, therefore, been assumed *that nontraumatic ruptures* are due to a high degree to degenerative changes in the semilunar cartilage. In this material it was found that the injury of the semilunar cartilage was clearly associated with trauma in 80 per cent of the cases both in the entire material and in the subjects who were followed-up. Information on several traumata in the same patient has not been specially noted, despite the fact that in a number of cases several injuries were mentioned. In athletes, on the other hand, there may have been information on only one injury, although it is known that, repeated traumata of the knees are usual, e. g. in footballers.

Comments

The frequency of traumatic ruptures of the semilunar cartilage reported earlier (table 7) and that reported in the present investigation were about the same.

TABLE 7. *Percentage traumatic ruptures of the semilunar cartilage according to different authors*

Authors	Per cent	Authors	Per cent
Key & Stromberg (1930)	93 7	Barfod & Bierring (1956)	85 7
Brechling (1942)	75 0	Scheibe (1963)	77.9
Sjovall (1942)	91.6	Barta & Perjés (1965)	79 8
Nitter (1946)	97.6	McLaughlin (1966)	92 8
Aarstrand (1954)	73.2		

6. INJURIES IN ATHLETES

Twenty-eight per cent of all operated patients related the rupture of the semilunar cartilage directly to injury occurring in the course of athletics. The majority of these patients were men.

Comments

Other authors had an appreciably higher percentage of injuries connected with athletics (table 8) than that shown in this material. The number of patients stated in another Swedish investigation (Sjövall, 1942) agrees

terial was, therefore, divided, in respect of the observation period, into the following decades:

4—13 years, 14—23 years, 24—33 years, and 34—43 years. Table 11 shows the distribution of all the subjects followed up in the different observation-period groups. It was found that in 199 cases, or 41.1 per cent, the observation period was at least 14 years. In 73 cases, or 15.2 per cent, the observation period was at least 24 years.

TABLE 11 *Distribution of followed up patients with regard to observation period (in decades) M = males, F = females % = M + F.*

	Total		4—13 years		14—23 years		24—33 years		34—43 years	
	M	F	M	F	M	F	M	F	M	F
Number of cases	422	58	236	45	118	8	61	5	7	0
%	100 0		58 5		26 3		13 8		1.4	

Comments

On account of the differences in the classification of observation periods in other reports it was not possible to compare, in tabular form, frequencies of subjects followed up in the different observation-period groups with the corresponding frequency in the present material. If, however, the frequency figures in the different observation periods given above are compared with earlier investigations (table 2), it will be found that this material is comparable with other materials with regard to the length of the observation period and to the number of cases in the different observation-period groups.

then the latency period was calculated from the first injury reported. Six months have been taken as the limit between a short and a long latency period. Many other authors have used the same limit. The number of patients in the group with a latency period exceeding 6 months was larger than the number of patients in groups 0—1 and 1—6 months. On the other hand, if all the patients operated during the first half year were taken together, it was found that these formed a somewhat larger group compared with the patients who were operated on after a latency period of half a year.

Comments

In several reports no distribution with regard to the latency period is given. Table 10 shows the distribution reported by some authors. In a number of series a contrary relation is reported, e. g. a larger number of patients operated after a latency period of 6 months. The differences, however, are relatively small and the observations are based on materials of different size. Early diagnosis and, consequently, early operation in recent years, as well as longer expectancy prior to operation adopted by some surgeons, can also account for these differences.

TABLE 10 *Distribution of the materials of different authors with regard to the latency period*

Authors	Under 6 months		Over 6 months	
	Number	%	Number	%
Key & Strömberg (1930)	19	43.2	25	56.8
Dengler (1938)	48	64.8	26	35.2
Sjövall (1942)	66	46.2	77	53.8
Barfod & Bierring (1956)	51	46	59	54
Herschmann (1965)	91	55.2	74	44.8
Jackson (1968)	210	36.4	367	63.6

8. OBSERVATION PERIOD

In view of the fact that the follow-up investigation was begun in 1965 and all the patients operated in 1960 were included in the material, the shortest observation period was somewhat longer than 4 years. The ma-

was given in radiological reports, for example, in connection with arthrography.

Injuries of the collateral ligaments, injuries of the cruciate ligaments, chondromalacia patellae, osteochondritis dissecans or *osteoarthritis* in the knee joint in connection with the operation were recorded only in such cases where these were mentioned in the operation report.

Postoperative complications in the form of *haemarthrosis* or *persisting effusion* were noted if the hospital records contained definite information in this respect. *Signs of infection* were recorded only if, in connection with a rise in temperature, information was also given, e.g. concerning increased local temperature and/or redness in the operating area. No case of extensive supuration was recorded in the whole material.

Postoperative fixation with some kind of splint or circular plaster cast was only noted if this had been recorded. Similarly, the time when the patient was first allowed to bear weight, and the *duration of the postoperative hospitalization* were also recorded.

If definite information was available for *postoperative muscular training*, this was recorded as well.

The type of surgical procedure, such as partial or total extirpation of the semilunar cartilage was also noted.

2. FOLLOW-UP INVESTIGATION

a Clinical examination

Subjective complaints were recorded on a standardized form in accordance with scheme I with + if the patient stated any. Each question was recorded separately. If a patient stated in answer to a question that he had considerable trouble, this was recorded by ++, and if the trouble was very pronounced with +++.

Objective findings were tested by inspection and palpation. The range of movement was measured from the maximal extended position (0°) to the maximal actively flexed position. Signs of cruciate ligament instability was tested with the knee at about 90° flexion position and the foot fixed. Lateral instability was tested with the knee in the extended position. To test the muscular strength of the knee the patient was asked to stand on one leg and from the maximal extended position to bend the knee to a squatting position from which he could rise without supporting himself with his hands or with the other leg. The angle between the initial posi-

CHAPTER III

Methods

The material was collected by studying the hospital register for the patients admitted during the years 1921—1960. A double control was obtained also by checking the operation register for the same period. All the patient records were produced, and from these summaries were made of the most important details of the case histories, of the entire operation reports and of the postoperative data, and transferred to punched cards. At the follow-up a scheme number 1 (p. 26) was used for the recording of subjective complaints, objective clinical findings, and information on the type of occupation as well as athletic activities after operation. Information whether the patient had had to change to lighter work after the operation, and the reasons for this were also noted. A roentgenologic examination was also made at the follow-up investigation.

1. DATA FROM HOSPITAL RECORDS

Lockings were recorded only if data on these occurred in the hospital records; the frequency of the lockings was not noted.

Effusion was recorded only if the case records contained the relevant data or if exudate was established and recorded by the examining physician or the surgeon.

Haemarthrosis was noted only provided the data were connected with puncture or when operation was performed in close association with trauma.

Because in this hospital the roentgen films are usually discarded after 10 years it was only possible to record the data on *preoperative roentgenologic osteoarthritis* in those cases where information on such changes

was given in radiological reports, for example, in connection with arthrography.

Injuries of the collateral ligaments, injuries of the cruciate ligaments, chondromalacia patellae, osteochondritis dissecans or *osteoarthritis* in the knee joint in connection with the operation were recorded only in such cases where these were mentioned in the operation report.

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a. *Clinical examination*

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Because in this hospital the roentgen films are usually discarded after 10 years it was only possible to record the data on *preoperative roentgenologic osteoarthritis* in those cases where information on such changes

When assessing the osteoarthritic signs on the radiographies, the degree of osteoarthritis was indicated by 0, +, ++, or +++, according to the following principles:

Marginal osteophytes:

0 = no signs of accentuation of the condylar margins, on the eminentia, in the fossa intercondyloidea or on the margins of the patella.

1 + = slight accentuation at the above-mentioned places of "Rauber's sign" type.

2 + = a distinct prolongation of the condylar margins or eminentia, in the fossa intercondyloídea or on the margins of the patella.

3 + = advanced osteophytes at the above-mentioned places.

Narrowing of the joint space was assessed by comparing radiographies with and without weight bearing on the knee, and was recorded as 0, if no difference could be demonstrated for certain. If a distinct narrowing of the joint space could be seen when weight bearing, but this was less than half the height of the joint space with the knee unloaded, this was indicated by 1 +. If the difference in the height of the joint space on weight bearing amounted to more than half of that with the knee at rest, but a joint space still existed, this was recorded by 2 +. A complete obliteration of the joint space when standing was recorded by 3 +. A distinct lateral subluxation of the femur in relation to the tibia was specially noted.

The occurrence of flattening of the surface of the femoral condyles was recorded, without any special grading, by +.

The occurrence of sclerosis, especially in the condyles of the tibia, as well as of cystic formations, was recorded, also without any grading, by +.

The roentgenologic findings were transferred only to computer cards.

It must be mentioned here that, in general, when classifying the data obtained from the study of the various parameters examined in this investigation, special care was taken to use classification criteria corresponding as much as possible to those used by the majority of earlier authors

3. STATISTICAL METHODS

For the statistical treatment of obtained differences between 2 or more comparisons the chi-square (X^2) method was used for testing the probability of differences in frequency of occurrence or non occurrence of the

tion and the squatting position was measured and noted. The test was performed on both the operated and the nonoperated leg. The thigh girth was measured 15 cm above the upper margin of the patella.

Besides these subjective complaints and objective findings, it was recorded whether the patient practised any kind of sport after the operation, and whether, on account of his articular trouble, he had been compelled to change his occupation for work that required less knee strain. When estimating the degree to which the work affected the knee, one had to depend to a great extent on the statements made by the patient himself.

The data on the subjective complaints and the objective findings and on sport and occupation after operation were transferred to a new scheme number 2 (p. 27). In this connection, with regard to the objective findings, the differences between the operated and the nonoperated knee were taken into account. These differences were recorded. Thus, for example, obtained differences in extention-flexion range between the 2 knees were divided into two groups: differences below or at most 10°, and differences exceeding 10°. The muscular strength of the knee was considered to be reduced if the difference in the ability to rise from the squatting position was greater than 10°. Muscular atrophy was regarded as present in the operated leg, and was recorded, if the difference between the thigh girth of the operated and of the nonoperated leg was 2 cm or more. These data were transferred to both punched cards and computer cards.

b. Roentgenologic examination

At the time of the follow-up investigation both knees were radiologically examined in the Department of Diagnostic Radiology II at the Regional Hospital in Linkoping. This examination was made with the patient in both the lying and the standing position with weight bearing on both knees. The importance of radiological examination in the standing position was previously emphasized by Fairbank (1948), and later by Ahlbäck (1968), Bauer (1968) and Bauer & al. (1969) among other authors.

All radiographies were assessed by one and the same senior radiologist, with regard to the reduction of joint space, marginal osteophytes, sclerosis, flattening of the femoral condyle and subluxation. The results were tabulated in accordance with scheme number 3 (p. 27).

In order to exclude any subjective influence on the assessments the radiologist did not know which knee and which semilunar cartilage had been operated on.

Increased skin temperature
Soft tissue swelling
Hypertrophied "Hoffa"
Capsule thickening
Effusion
Tenderness medially (operated knee)
Tenderness laterally („ „)
Other localisation of tenderness (operated knee)
Moderate crepitation
Pronounced „
Lateral instability
Cruciate ligament instability
Quadriceps atrophy (more than 2 cm)
Decreased range of active extension (up to 10°)
„ „ „ „ „ (more than 10°)
„ „ „ „ flexion (up to 10°)
„ „ „ „ „ (more than 10°)
„ muscular strength (more than 10°)

Scheme No 2 for registration of the objective findings when the operated knee is compared with the nonoperated knee.

	Operated knee	Nonoperated knee
Osteophytes medial femur condyle		
„ „ tibia „		
„ lateral femur „		
„ „ tibia „		
„ fossa intercond medially		
„ „ „ laterally		
„ eminentia tibiae medially		
„ „ „ laterally		
Sclerosis medial femur condyle		
„ lateral „ „		
„ medial tibia „		
„ lateral „ „		
Planning medial femur condyle		
„ lateral „ „		
Narrowing medial joint space		
„ lateral „ „		
Osteophytes patella		

Scheme No 3 for registration of the roentgenologic findings

different variables examined. The obtained values of X^2 for each individual comparison are given in the text, followed by the level of probability and the degrees of freedom (d. f.). The level of probability was evaluated as follows:

$p > 0.05$ = non significant
$p < 0.05$ = almost significant = *
$p < 0.01$ = significant = **
$p < 0.001$ = highly significant = ***

Pain at rest
Pain at weight bearing
Weakness feeling
Walking disability upstairs or uphills
Lockings
Other complaints

Increased skin temperature
Soft tissue swelling
Hypertrophied "Hoffa"
Capsule thickening
Effusion
Tenderness medially (operated knee)
" " (" ")
Other localisation of tenderness (operated knee)
Crepitation
Range of motion (operated knee)
" " " (non " ")
Lateral instability
Cruciate ligament instability
Muscular strenght operated knee
" " non " "
Thigh girth (operated side)
" " (non " ")

Athletic activity after operation
Moved to lighter work after operation
Mainly sitting work
Moderately knee straining work
Severely knee straining work

Scheme No 1 for registration of the subjective complaints and objective findings

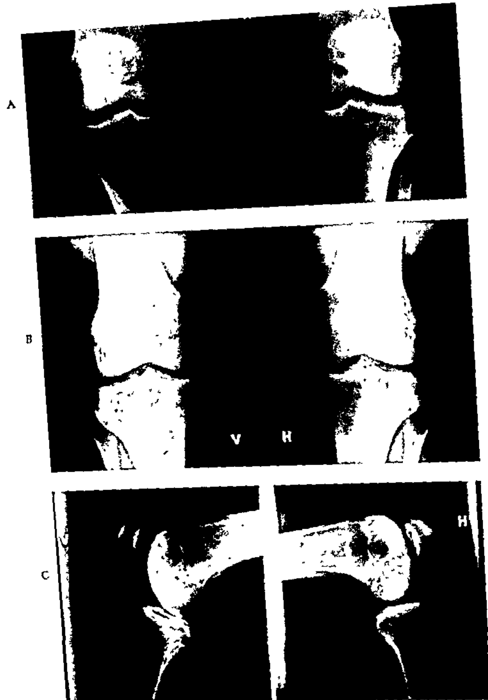


FIG 4 Characteristic radiographies of cases allocated to *group 0 normal knees* (medially meniscectomized knee at the left) A. Frontal projection of both knees with the patient in the lying position B Frontal projection with the patient in standing position with weight bearing on both knees C. Side projection of both knees in lying position.

CHAPTER IV

Results of follow-up examination of patients with total extirpation of the semilunar cartilage

1. ROENTGENOLOGIC RESULTS

Previous investigations

As shown in table 12 the variation in the frequency of degenerative arthritis after meniscectomy reported by earlier investigators is considerable. These differences may to some extent be due to varying bases of assessment and partly to unequal observation periods in the various materials.

Besides those referred to in table 12 a number of authors have reported frequencies, varying between 8 and 25 per cent without grading the observed signs of degenerative arthritis in detail (Key & Strömberg 1930, Brechling 1942, Lagergren 1953, Saugmann-Jensen 1963, Pelzl & Rueff 1969).

Franke (1966) stated that he was able to show a higher frequency of osteoarthritis in females than in males.

Own observations

Tables 13 and 14 show the frequency of different signs of osteoarthritis. In classifying the results in these tables, patients operated for a medial

TABLE 12 *The frequency of roentgenologic signs of degenerative arthritis according to different authors*

Authors	Total number of cases	Group 0 %	Group I %	Group II %	Group III %
Nitter (1946)	35	65.7		22.9	11.4
Fuss (1951)	100	44.0	43.0	13.0	0
Streli (1955)	82	69.5	15.9	14.6	0
Rothascher (1960)	353	64.[illegible]	28.9	5.1	1.7
Scheibe (1963)	110	53.6	19.1	22.7	4.6
Leuschner & Weickert (1964)	85	31.3	49.4	19.3	
Franke (1966)	103	21.4	39.8	19.4	19.4
Jackson (1968)	577	77.0		23.0	

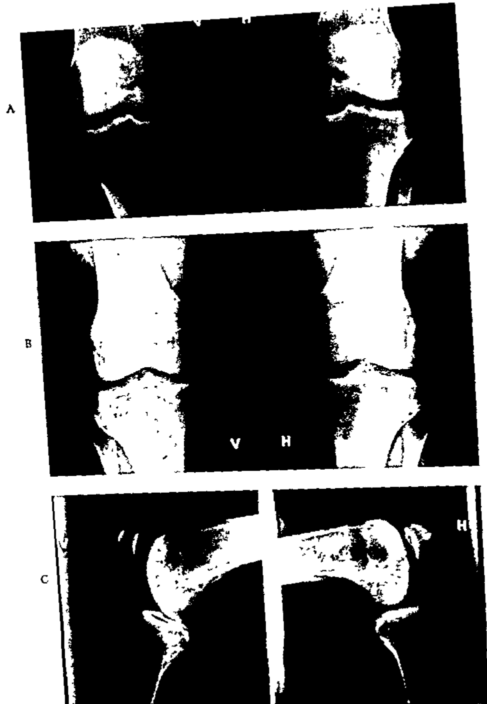


FIG 4 Characteristic radiographies of cases allocated to *group 0 normal knees* (medially meniscectomized knee at the left). A. Frontal projection of both knees with the patient in the lying position B Frontal projection with the patient in standing position with weight bearing on both knees C. Side projection of both knees in lying position.

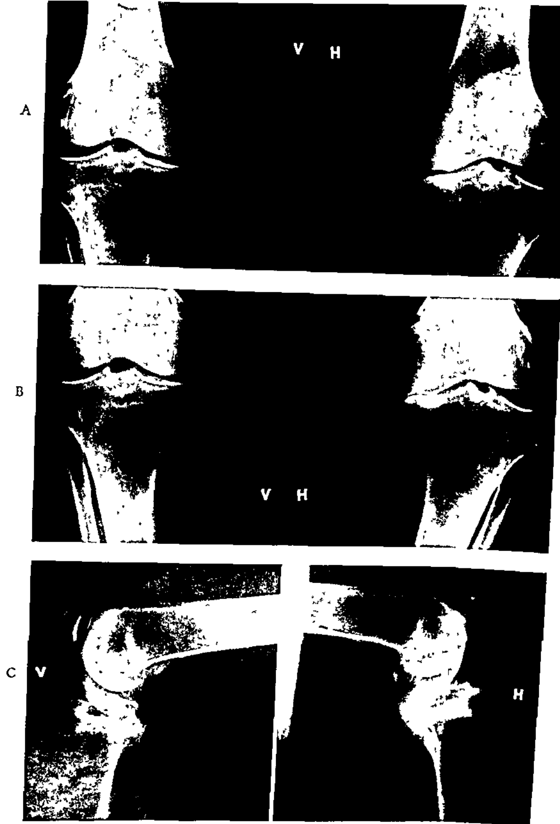


FIG. 7 Characteristic radiographies of cases allocated to *group III* knees with *severe osteoarthritis* (medially meniscectomized knee at the right) A. Frontal projection of both knees [illegible] t in the lying position. B Frontal projection with the patient in stan[illegible] g on both knees. C. Side projecti[illegible] both kn[illegible] 'ng position.

semilunar cartilage rupture, with osteophytes present on the medial aspect of the tibia, of degree + + in the operated and + in the nonoperated knee, were placed with regard to osteophytes medially on the tibia, in column 8 in table 13. The observed higher frequency of osteoarthritic signs in the operated than the nonoperated knee is significant as shown in table 15. Thus the roentgenologic signs of osteoarthritis following total extirpation of the semilunar cartilage are significantly higher in the operated than in the nonoperated control knee.

In order to be able to compare the obtained results, in respect of roentgenologically demonstrable degenerative arthritis, with those of other authors, the material has been divided into four groups. In this grouping, following the suggestion of earlier authors (Ahlbäck 1968, Danielsson & Hernborg 1969), more attention has been paid to narrowing of the joint space, flattening of the femoral condyle and sclerosis than to the sum of the osteophytes.

Group 0: this group comprises apparently *normal knees*. (Fig. 4)

Group I: here were allocated knees with radiological signs of *initial osteoarthritis* as slight decrease of the joint space without signs of skeletal changes, other than some minor accentuation of the condylar margins of type 1 +. (Fig. 5)

Group II: this contains knees with signs of *pronounced osteoarthritis* such as marked reduction of the joint space with some flattening of the femoral condyle or sclerosis. (Fig. 6)

Group III: here the knees had signs of *severe osteoarthritis* with extensive reduction or total obliteration of the joint space, cystic formations, flattening of the femoral condyles, sclerosis, severe ostophytes and distinct subluxation of the femur in relation to the tibia. As a whole the knees of this group showed signs of extensive osteoarthritic destruction. (Fig. 7)

In view of the difficulties in obtaining a satisfactory evaluation of the radiographies, with necessary requirements of objectivity, when based on the estimations of one person alone, the roentgenograms were evaluated by another senior radiologist as well. He was asked to classify the roentgenologic findings which, according to his opinion, corresponded to the groups of classification referred to above. He obtained no information regarding the results of the first radiologist, and the same measures of security were used to avoid influencing his judgement. The results of the second radiologist were further treated and analysed statistically with regard to the "roentgenologic findings" in the same way as those of the first radiologist. Thus a double control of the estimation of the radiologi-

cal results was achieved. A comparison of the data obtained from both evaluations showed a striking similarity, with only minor divergencies, which will be mentioned separately in the following.

Table 16 shows the number of cases in different groups with regard to the degree of osteoarthritic changes according to the above mentioned criteria. Here it may be pointed out that in 17 patients belonging to group 0 slight signs of degenerative arthritis were found in the nonoperated knee. In group I two patients had more osteoarthritic signs in the nonoperated knee. In groups II and III all the patients had more pronounced signs of degenerative arthritis in the operated knee than in the nonoperated knee. If groups II and III in table 16 are taken together to form one group with distinct osteoarthritic changes in the operated knee, then these cases will amount to only 10.8 per cent[1]) of all the knees subjected to total extirpation of the semilunar cartilage. In 4 among the nonoperated knees, i. e. in 0.9 per cent there were, at the time of the follow-up, roentgenologic signs of degenerative arthritis corresponding to group II and III. In this respect the difference between operated and nonoperated knees is highly significant ($X^2 = 226.52^{***}$ d. f. = 2). A comparison between laterally and medially meniscectomized knees showed that osteoarthritic changes of groups II and III were present in 8.7 and 11.3 per cent[1]) of the cases respectively. This difference is not significant. When females were compared with males, 19.6 per cent of the former had osteoarthritic changes and 9.6 per cent of the latter.[1]). This difference is almost significant ($X^2 = 5.81^{*}$ d. f. = 2).

TABLE 16. *Distribution of the totally meniscectomized and nonoperated knees in different groups of roentgenologic osteoarthritis M = males, F = females % = M + F.*

Operated meniscus	Total number		Group 0 Number		Group 0 %	Group I Number		Group I %	Group II Number		Group II %	Group III Number		Group III %
	M	F	M	F		M	F		M	F		M	F	
Medial	327	44	178	16	52.3	116	19	36.4	27	6	8.9	6	3	2.4
Lateral	57	12	32	8	58.0	21	2	33.3	4	2	8.7	0	0	0
Total	384	56	210	24		137	21		31	8		6	3	
	440		234		53.2	158		36.0	39		8.8	9		2.0
Nonoperated	440		427		97.0	9		2.1	3		0.7	1		0.2

1) According to the evaluation of the second radiologist (page 29) the fre[illegible] of radiologic osteoarthritis was: All total meniscectomized knees 10.2 per cent [illegible]lly meniscectomized knees 10.8 per cent, laterally meniscectomized knees 7.2 per [illegible]nt, for males 9.1 per cent and for females 17.8 per cent

Comments

If according to Jackson (1968), groups 0 and I are considered to form together a "normal" group, and groups II and III are combined to form a "degenerative" group, it will be found that both the number and the percentage of knees belonging to the latter group in the present material are lower than in the reports of earlier authors, with the exception of Rothascher (1960) (table 12).

The previously reported occurrence of osteoarthritic changes following total extirpation of the semilunar cartilage was verified and statistically ascertained by the results presented here.

Observed differences between knees operated for rupture of the medial or the lateral semilunar cartilage respectively were not significant. The difference between males and females as regards the frequency of roentgenologic osteoarthritis in the operated knee, was found significant. Thus, earlier statements of a higher frequency of osteoarthritis in females than in males following meniscectomy (Franke 1966) could be verified from the present results.

a. AGE AT THE TIME OF OPERATION

Previous investigations

The frequency of roentgenologic osteoarthritic changes following meniscectomy has been especially correlated with the patient's age at the time of operation only by a few authors. Varying results have been reported. Thus, it has been stated that by preference patients over 45 years of age should not be subjected to meniscectomy on account of the substantially greater risk of development of osteoarthritis when operating patients of advanced age (Scheibe 1963, Herschmann 1965). On the other hand, it has been considered that the patient's age at operation is of no importance for the development of roentgenologic osteoarthritis (Nitter 1946, Saugmann-Jensen 1963).

Own observations

In the entire material of total meniscectomies it was found, on correlating the roentgenologic findings with age at operation, that patients over 41 years had a higher frequency with distinct degenerative arthritis of groups

cal results was achieved. A comparison of the data obtained from both evaluations showed a striking similarity, with only minor divergencies, which will be mentioned separately in the following.

Table 16 shows the number of cases in different groups with regard to the degree of osteoarthritic changes according to the above mentioned criteria. Here it may be pointed out that in 17 patients belonging to group 0 slight signs of degenerative arthritis were found in the nonoperated knee. In group I two patients had more osteoarthritic signs in the nonoperated knee. In groups II and III all the patients had more pronounced signs of degenerative arthritis in the operated knee than in the nonoperated knee. If groups II and III in table 16 are taken together to form one group with distinct osteoarthritic changes in the operated knee, then these cases will amount to only 10.8 per cent[1]) of all the knees subjected to total extirpation of the semilunar cartilage. In 4 among the nonoperated knees, i. e. in 0.9 per cent there were, at the time of the follow-up, roentgenologic signs of degenerative arthritis corresponding to group II and III. In this respect the difference between operated and nonoperated knees is highly significant ($X^2 = 226.52^{***}$ d. f. = 2). A comparison between laterally and medially meniscectomized knees showed that osteoarthritic changes of groups II and III were present in 8.7 and 11.3 per cent[1]) of the cases respectively. This difference is not significant. When females were compared with males, 19.6 per cent of the former had osteoarthritic changes and 9.6 per cent of the latter.[1]). This difference is almost significant ($X^2 = 5.81^{*}$ d. f. = 2).

TABLE 16 *Distribution of the totally meniscectomized and nonoperated knees in different groups of roentgenologic osteoarthritis M = males, F = females. % = M + F.*

Operated meniscus	Total number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
	M	F	M	F		M	F		M	F		M	F	
Medial	327	44	178	16	52.3	116	19	36.4	27	6	8.9	6	3	2.4
Lateral	57	12	32	8	58.0	21	2	33.3	4	2	8.7	0	0	0
Total	384	56	210	24		137	21		31	8		6	3	
	440		234		53.2	158		36.0	39		8.8	9		2.0
Nonoperated	440		427		97.0	9		2.1	3		0.7	1		0.2

[1]) According to the evaluation of the second radiologist (page 29) the frequency of radiologic osteoarthritis was: All total meniscectomized knees 10.2 per cent, medially meniscectomized knees 10.8 per cent, laterally meniscectomized knees 7.2 per cent, for males 9.1 per cent and for females 17.8 per cent

b. LATENCY PERIOD

Correlation of the total results of a follow-up investigation with the time that elapses between an adequate trauma or the onset of the first symptoms and the time of operation — which has been named here the latency period — has been taken up for discussion by several authors. Moreover, the existence of roentgenologic signs of osteoarthritis has also been correlated with the length of the latency period by some authors. A number of investigators have claimed that a clear-cut connection exists between the occurrence of osteoarthritis and a long latency period (Nitter 1946, Barfod & Bierring 1956, Scheibe 1963, Mohing 1966, Franke 1966, Gear 1967, Pelzl & Rueff 1969). These statements, however, are not based on statistical verification of the results. On the other hand, it has also been held that no connection exists between higher frequency of degenerative arthritis and a long latency period. (Saugmann-Jensen 1963, Allegreni & Dell'Orto 1965, Jackson 1968, Tapper & Hoover 1969). Among the latter authors only Jackson (1968) and Tapper & Hoover (1969) have

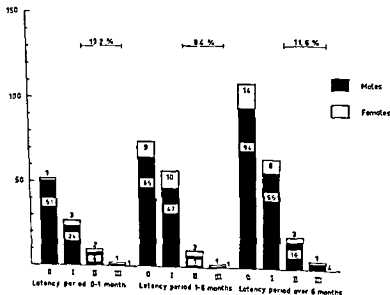


FIG 8 Number of followed up meniscectomized patients distributed by different groups of roentgenologic osteoarthritis and latency periods Percentage of osteoarthritic cases given at the top.

II and III than those under 41 (table 17). This difference is almost significant ($X^2 = 8.80$; d. f. = 2). The frequency of osteoarthritis was also higher in patients subjected to medial meniscectomy when over 41 than those under 41 years at operation. This difference was also almost significant ($X^2 = 7.66$; d. f. = 2). In patients subjected to lateral meniscectomy the frequency of osteoarthritis was found to be higher in subjects over than under 41 years at operation, but this difference is not significant. A comparison was also done for men and women separately. For both males and females analysed separately the frequency of roentgenologic osteoarthritis was higher in cases where a total meniscectomy was performed on patients over 41 years than on those under 41. For men this difference is almost significant ($X^2 = 6.76$; d. f. = 2), but not for women.[2])

Comments

In this material the frequency of osteoarthritic changes was higher in patients over 41 subjected to total meniscectomy than in those under 41 at the time of operation. The results are in agreement with the findings reported by Scheibe (1963) and Herschmann (1965). The differences were statistically significant for all patients subjected to total meniscectomy, for medial meniscectomies taken separately, as well as for total meniscectomies in males. For laterally meniscectomized knees, and for females examined separately, observed differences were not significant.

TABLE 17 *Distribution of the totally meniscectomized knees in different groups of roentgenologic osteoarthritis with regard to age at operation M = males, F = females % = M + F*

Operated meniscus	Age at operation	Total Number M	F	Group 0 Number M	F	%	Group I Number M	F	%	Group II Number M	F	%	Group III Number M	F	%
Medial	Under 41 years	241	23	140	10	56.8	75	11	32.6	24	2	9.8	2	0	0.8
Lateral	„ 41 „	49	7	28	6	60.7	18	0	32.1	3	1	7.2	0	0	0
Total	Under 41 years	290	30	168	16	57.5	93	11	32.5	27	3	9.4	2	0	0.6
Medial	Over 41 years	86	21	38	6	41.2	41	8	45.8	3	4	6.5	4	3	6.5
Lateral	„ 41 „	8	5	4	2	46.2	3	2	38.5	1	1	15.3	0	0	0
Total	Over 41 years	94	26	42	8	41.7	44	10	45.0	4	5	7.5	4	3	5.8

[2]) In this respect the results obtained from the evaluation of the roentgenologic findings by the second radiologist (page 29) were divergent. Thus, no significant difference in the frequency of roentgenologic signs of osteoarthritis existed between men operated before or after 41 years of age.

c. THE TYPE OF TRAUMA

Opinions regarding the importance of the aetiologic factor responsible for the rupture of the semilunar cartilage for the occurrence of osteoarthritis diverge widely. It has been stated that trauma as such predisposes to more pronounced osteoarthritis, while the degree of degeneration of the semilunar cartilage is of no importance (Fuss 1951, Tapper & Hoover 1969). On the other hand, there are authors who assert that injuries of the semilunar cartilage without definite trauma are due to increased degeneration of the cartilage and, consequently, of the entire knee. After meniscectomy such a knee is more prone to develop roentgenologic osteoarthritis compared with a healthy knee with traumatic injury of the semilunar cartilage (Rothascher 1960, Franke 1966).

Own investigations

Among the patients subjected to total meniscectomy 80.9 per cent reported trauma in the history. However, only 30.0 per cent could define the type of trauma, which indicates the difficulty of obtaining reliable information on this matter. These latter patients were divided into different groups according to the type of the main trauma reported, namely in combination with rotation, abduction, adduction or hyperextension of the knee. In 19.1 per cent no certain data regarding the mechanism of the injury were obtainable. Table 18 shows the distribution of the material with regard to traumatic and nontraumatic cases as well as to the type of trauma correlated with the degree of osteoarthritis. The traumatic and

TABLE 18 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis in respect of the type of knee injury*
M = males, F = females % = M + F

Factor trauma	Total Number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
Defined trauma	M	F	M	F		M	F		M	F		M	F	
Rotation	61	4	32	2		25	1		4	0		0	1	
Abduction	20	2	14	0		4	2		2	0		0	0	
Adduction	29	6	13	5		13	1		3	0		0	0	
Hyperextension	9	1	6	1		3	0		0	0		0	0	
Total	119	13	65	8	55.3	45	4	37.1	9	0	6.8	0	1	0.8
Non-defined trauma	196	28	103	9	50.0	71	13	37.5	17	6	10.3	5	0	2.2
No certain ,,	69	15	42	7	58.3	21	4	29.8	5	2	8.3	1	2	3.6
Total	384	56	210	24		137	21		31	8		6	3	

verified their results statistically. Wynn Parry et al. (1958) reported an appreciably higher frequency of osteoarthritic signs at operation in patients with a long latency period.

Own observations

By dividing the material according to the length of the latency period into 3 different groups, namely, under 1 month, 1—6 months and over 6 months and with a demarcation line at 6 months between a short and a long latency period, a distribution of total meniscectomies is obtained as demonstrated in fig. 8. The lowest frequency of osteoarthritic knees occurs within the latency period of 1—6 months and the highest percentage in the group operated with a maximal latency period of 1 month. These differences in the frequency of osteoarthritis are, however, small and not significant. This applies to all total meniscectomies. Nor were any significant differences observed on comparing separately, medially and laterally meniscectomized knees with the length of the latency period. Totally meniscectomized knees have been tested also for males and females separately with regard to the length of latency period. Existing differences in this respect were not significant. The importance of the latency period for frequency of osteoarthritis was also tested separately for totally meniscectomized knees in patients operated on before and after they were 41 years old respectively. The length of the latency period did not influence the results significantly.

Comments

Although certain percentage differences were found on correlating the occurrence of osteoarthritis with the length of latency period, these differences were not significant. It can therefore be concluded that the length of the latency period does not play such an important role for the occurrence of osteoarthritis in a meniscectomized knee as has been stated earlier (Nitter 1946, Barfod & Bierring 1965, Scheibe 1963, Mohing 1966, Franke 1966, Gear 1967, Pelzl & Rueff 1969). The conception that the length of the latency period does not play any part in the occurrence of osteoarthritis in a meniscectomized knee has thus been verified (Saugmann-Jensen 1963, Allegreni & Dell'Orto 1965, Jackson 1968, Tapper & Hoover 1969). It must be pointed out, however, that these observations concern comparisons between short and long latency periods with a borderline at 6 months. It is possible that other correlations would be found if this limit was either increased or decreased.

c. THE TYPE OF TRAUMA

Opinions regarding the importance of the aetiologic factor responsible for the rupture of the semilunar cartilage for the occurrence of osteoarthritis diverge widely. It has been stated that trauma as such predisposes to more pronounced osteoarthritis, while the degree of degeneration of the semilunar cartilage is of no importance (Fuss 1951, Tapper & Hoover 1969). On the other hand, there are authors who assert that injuries of the semilunar cartilage without definite trauma are due to increased degeneration of the cartilage and, consequently, of the entire knee. After meniscectomy such a knee is more prone to develop roentgenologic osteoarthritis compared with a healthy knee with traumatic injury of the semilunar cartilage (Rothascher 1960, Franke 1966).

Own investigations

Among the patients subjected to total meniscectomy 80.9 per cent reported trauma in the history. However, only 30.0 per cent could define the type of trauma, which indicates the difficulty of obtaining reliable information on this matter. These latter patients were divided into different groups according to the type of the main trauma reported, namely in combination with rotation, abduction, adduction or hyperextension of the knee. In 19.1 per cent no certain data regarding the mechanism of the injury were obtainable. Table 18 shows the distribution of the material with regard to traumatic and nontraumatic cases as well as to the type of trauma correlated with the degree of osteoarthritis. The traumatic and

TABLE 18 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis in respect of the type of knee injury*
M = males, F = females % = M + F

Factor trauma	Total Number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
Defined trauma	M	F	M	F		M	F		M	F		M	F	
Rotation	61	4	32	2		25	1		4	0		0	1	
Abduction	20	2	14	0		4	2		2	0		0	0	
Adduction	29	6	13	5		13	1		3	0		0	0	
Hyperextension	9	1	6	1		3	0		0	0		0	0	
Total	119	13	65	8	55.3	45	4	37.1	9	0	6.8	0	1	0.8
Non-defined trauma	196	28	103	9	50.0	71	13	37.5	17	6	10.3	5	0	2.2
No certain "	69	15	42	7	58.3	21	4	29.8	5	2	8.3	1	2	3.6
Total	384	56	210	24		137	21		31	8		6	3	

nontraumatic cases correlated with the degree of degenerative arthritis are given in fig. 9. Only slight, not significant differences in the frequency of osteoarthritis were found on comparing total meniscectomies in traumatic and nontraumatic cases.

Comments

With regard to the frequency of osteoarthritis no significant difference existed between knees where rupture of the semilunar cartilage was due to trauma or not. This verifies the conception that trauma is not import-

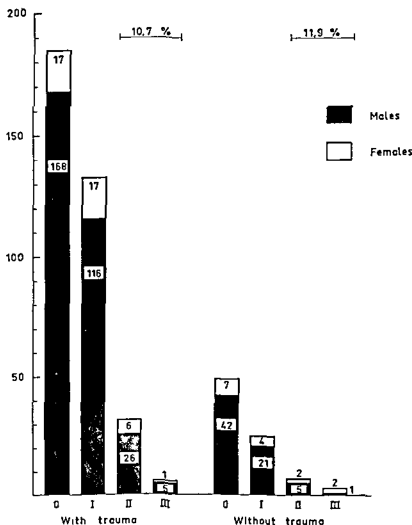


FIG 9 Number of followed-up meniscectomized patients distributed by different groups of roentgenologic osteoarthritis and factor trauma Percentage of osteoarthritic cases given at the top.

ant for the occurrence of ostearthritis after meniscectomy (Rothascher 1960, Franke 1966). On the other hand, it may also be said that the obtained results do not support the opinion of the above-mentioned authors, that rupture of the semilunar cartilage without trauma causes a higher frequency of roentgenologic osteoarthritis in the meniscectomized knee, because of generalized degenerative changes of the joint.

d. OBSERVATION PERIOD

Many authors consider that the length of the observation period is of importance for the occurrence of degenerative arthritis in a meniscectomized knee. They maintain, therefore, that an observation period of at least 15—20 years is required for a material to be considered representative (Nitter 1946, Streli 1955, Saugmann-Jensen 1963, Allegreni & Dell'Orto 1965, Mohing 1966, Jackson 1968). Other authors consider that there is no connection between the frequency of osteoarthritis and a long observation period (Brechling 1942, Fuss 1951, Barfod & Bierring 1956, Tapper & Hoover 1969).

Own investigations

As has been previously stated, the observation period has been divided into 10-year periods. The largest number of cases was found in the observation period 4—13 years. In the entire material there was a higher frequency of radiologic signs of degenerative arthritis of groups II and III in patients with an observation period over 24 years than for those with one under 24 years (table 19). The increase in the frequency of osteo-

TABLE 19 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis with regard to the observation period in decades M = males, F = females % = M + F*

Observation period	Total Number		Group 0 Number		Group 0 %	Group 1 Number		Group 1 %	Group II Number		Group II %	Group III Number		Group III %
	M	F	M	F		M	F		M	F		M	F	
4—13 years	219	44	125	21	55 5	60	16	36 5	10	6	6 1	4	1	1 9
14—23 „	106	8	59	3	54 4	37	3	35 1	9	0	7 9	1	2	2 6
24—33 „	53	4	23	0	40 3	17	2	33 3	12	2	24 6	1	0	1 8
34—43 „	6	0	3	0	50 0	3	0	50 0	0	0	0	0	0	
Total	384	56	210	24		137	21		31	8		6	3	

nontraumatic cases correlated with the degree of degenerative arthritis are given in fig. 9. Only slight, not significant differences in the frequency of osteoarthritis were found on comparing total meniscectomies in traumatic and nontraumatic cases.

Comments

With regard to the frequency of osteoarthritis no significant difference existed between knees where rupture of the semilunar cartilage was due to trauma or not. This verifies the conception that trauma is not import-

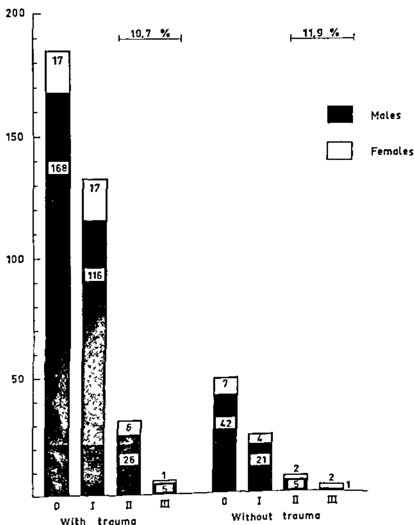


FIG. 9 Number of followed-up meniscectomized patients distributed by different groups of roentgenologic osteoarthritis and factor trauma Percentage of osteoarthritic cases given at the top.

tive with regard to the roentgenologic signs of osteoarthritis (Nitter 1946, Streli 1955, Saugmann-Jensen 1963, Allegreni & Dell-Orto 1965, Mohing 1966, Jackson 1968).

Moreover, it is obvious from the studies of the nonoperated knee mentioned above, that the higher frequency of roentgenologic osteoarthritis with increasing time of observation does not only depend on the increasing age of the patient. Thus, it has been observed that the frequency of osteoarthritis was significantly higher in the operated than the nonoperated knee in all the groups of observation period.

e. OTHER FACTORS THAT POSSIBLY PROMOTE OCCURRENCE OF OSTEOARTHRITIS

Besides the factors already analyzed there may be others too which possibly can contribute to the occurrence of roentgenologic osteoarthritis following meniscectomy. The results of other analyzed factors will be presented here.

Clinical findings prior to operation, such as effusion, lockings, haemarthrosis or a combination of these occurred in 352 of the 440 cases or 80.4 per cent of total meniscectomies, distinctly more in the medially than in the laterally meniscectomized knees. No significant difference could be established in the frequency of osteoarthritis with regard to the presence or absence of preoperative clinical findings.

As has been previously stated, *roentgenologic signs of degenerative arthritis prior to operation* could be recorded only by means of the radiological reports. It was only in 36 out of 440 cases of totally meniscectomized knees that osteoarthritis had been reported. The frequency of degenerative arthritis at the follow-up investigation was significantly higher in patients with preoperative roentgenologic osteoarthritis than in those without ($X^2 = 36.41^{***}$ d. f. = 3). Among the 36 cases with preoperative roentgenologically demonstrable degenerative arthritis there were 9 knees which did not show any roentgenologic osteoarthritis at the follow up examination, these knees were regarded as belonging to group 0. This finding is in agreement with similar observations reported by Meier (1933) and Pelzl & Rueff (1969). A possible explanation of this regression of osteoarthritic changes may be, that a disturbing agent had been removed from the joint by meniscectomy.

arthritis for an observation period over 24 years is almost significant ($X^2 = 14.4^*$ d. f. = 6). For medially meniscectomized patients taken separately, there is also a significant increase in the frequency of osteoarthritis when the observation period exceeded 24 years ($X^2 = 9.5^*$ d. f. = 4). On the contrary, laterally meniscectomized knees do not show any significant differences in the frequency of osteoarthritis in relation to the length of the observation period. When correlating frequency of degenerative arthritis with length of the observation period for males and females separately, the males were found to have increased frequency when the observation period exceeded 24 years. The difference was significant ($X^2 = 13.39^{**}$ d. f. = 4). For the females no significant differences were observed.

TABLE 19 a. *Distribution of nonoperated knees in the different groups of roentgenologic osteoarthritis with regard to the observation period in decades. M = males, F = females. % = M + F.*

Observation period	Total Number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
	M	F	M	F		M	F		M	F		M	F	
4—13 years	219	44	216	42	98.1	3	2	1 9	0	0	0	0	0	0
14—23 „	106	8	104	6	96.5	2	0	1 7	0	1	0 9	0	1	0 9
24—43 „	59	4	55	4	93 6	2	0	3 2	2	0	3 2	0	0	0
Total	384	56	375	52		7	2		2	1		0	1	

As shown in table 19 a, increased frequency of degenerative arthritis occurs also in the nonoperated knee with the increase of time between the operation of the other knee and the follow-up examination. There was, further, a significantly higher frequency of osteoarthritis in the operated as compared with the nonoperated knee increasing with the period of observation, i. e. in the 4—13 years group ($X^2 = 134.04^{***}$ d. f. = 2); in the 14—23 years group ($X^2 = 54.92^{***}$ d. f. = 2); and in the 24—43 years group ($X^2 = 34.92^{***}$ d. f. = 2).

Comments

The results of this investigation show a significant increase in the frequency of roentgenologic signs of osteoarthritis for observation periods exceeding 24 years compared with those under 24 years. Thus, these results support the opinion that a material consisting of meniscectomized knees should have a sufficiently long observation period to be representa-

tive with regard to the roentgenologic signs of osteoarthritis (Nitter 1946, Streli 1955, Saugmann-Jensen 1963, Allegreni & Dell-Orto 1965, Mohing 1966, Jackson 1968).

Moreover, it is obvious from the studies of the nonoperated knee mentioned above, that the higher frequency of roentgenologic osteoarthritis with increasing time of observation does not only depend on the increasing age of the patient. Thus, it has been observed that the frequency of osteoarthritis was significantly higher in the operated than the nonoperated knee in all the groups of observation period.

e. OTHER FACTORS THAT POSSIBLY PROMOTE OCCURRENCE OF OSTEOARTHRITIS

Besides the factors already analyzed there may be others too which possibly can contribute to the occurrence of roentgenologic osteoarthritis following meniscectomy. The results of other analyzed factors will be presented here.

Clinical findings prior to operation, such as effusion, lockings, haemarthrosis or a combination of these occurred in 352 of the 440 cases or 80.4 per cent of total meniscectomies, distinctly more in the medially than in the laterally meniscectomized knees. No significant difference could be established in the frequency of osteoarthritis with regard to the presence or absence of preoperative clinical findings.

As has been previously stated, *roentgenologic signs of degenerative arthritis prior to operation* could be recorded only by means of the radiological reports. It was only in 36 out of 440 cases of totally meniscectomized knees that osteoarthritis had been reported. The frequency of degenerative arthritis at the follow-up investigation was significantly higher in patients with preoperative roentgenologic osteoarthritis than in those without ($X^2 = 36.41^{***}$ d. f. = 3). Among the 36 cases with preoperative roentgenologically demonstrable degenerative arthritis there were 9 knees which did not show any roentgenologic osteoarthritis at the follow up examination, these knees were regarded as belonging to group 0. This finding is in agreement with similar observations reported by Meier (1933) and Pelzl & Rueff (1969). A possible explanation of this regression of osteoarthritic changes may be, that a disturbing agent had been removed from the joint by meniscectomy.

Osteoarthritis and other secondary findings at operation were only described in the hospital records in a comparatively few cases (table 20). Statistical analysis of the effect of other secondary findings on the development of roentgenologic osteoarthritis after the operation was therefore not possible. Description of degenerative changes observed in the joint at the time of operation was, however, frequent and analysis with respect to this finding became possible.

The frequency of roentgenologic osteoarthritis was higher at the follow-up investigation in those patients who at operation had had demonstrable osteoarthritis compared with the patients without signs of it. The difference was highly significant ($X^2 = 24.04^{***}$ d. f. = 3). Here, it is also noteworthy that in 12 patients with osteoarthritis at operation, no signs of such a condition were found in radiographies taken at the follow-up examination.

TABLE 20. *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis with regard to the various operative findings. M = males, F = females.*

Operative findings	Group 0 Number		Group I Number		Group II Number		Group III Number	
	M	F	M	F	M	F	M	F
Injuries of coll. lig.	2	0	1	1	0	0	0	0
,, ,, cruc. ,,	3	0	2	0	0	0	0	0
Chondrom. patellae	1	1	5	1	2	0	1	0
Osteochondr dissec.	2	0	4	0	1	1	1	0
Osteoarthritis	11	1	12	6	6	2	3	1

Signs of infection after operation were recorded in 21 cases (4.8 per cent). One of these cases was allocated to group II and another to group III. *Effusion* persisting longer than 3 weeks postoperatively was noted in the hospital records in 15 cases; none of these cases belonged to group III and only one in group II. *Haemarthrosis* was recorded in 20 cases, with one case in group II and none in group III. The frequency of osteoarthritis at the follow-up investigation did not show any significant differences between patients with and without such postoperative complications.

According to the hospital records *muscular training* had been applied postoperatively in 199 cases or in 45.2 per cent of the total meniscectomies. The frequency of roentgenologic signs of osteoarthritis at the follow-

up investigation in patients who had had muscular training compared with those where data on such training were lacking, did not show any significant difference.

Splint fixation was applied in 167 cases and fixation by a plaster cast only in 4 operated patients. The frequency of degenerative arthritis was higher in patients with postoperative fixation than in those without fixation. The difference is almost significant ($X^2 = 10.8^*$ d. f. = 3).[3]

Patients who were *allowed to bear weight* on the operated leg first after the 2nd postoperative week had a higher frequency of osteoarthritic changes than those where weight bearing was allowed earlier. (Table 21). This difference is also almost significant ($X^2 = 10.07^*$ d. f. = 4).[4] This finding together with the observation that postoperative complications did not significantly affect the occurrence of osteoarthritis may indicate partly that restriction with weight bearing was probably due to different principles of treatment (Pelzl & Rueff 1969), and partly that early weight bearing does not promote the occurrence of osteoarthritis.

TABLE 21 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis in respect of the time when weight bearing was allowed postoperatively M = males, F = females % = M + F.*

Postop weight bearing	Total Number		Group 0 Number		Group 0	Group I Number		Group I	Group II Number		Group II	Group III Number		Group III
	M	F	M	F	%	M	F	%	M	F	%	M	F	%
Within 1 week	40	2	21	2	54.8	18	0	42.8	1	0	2.4	0	0	0
„ 8—14 days	258	31	150	14	56.7	82	13	32.9	22	4	9.0	4	0	1.4
After 2 weeks	86	23	39	8	43.1	37	8	41.3	8	4	11.0	2	3	4.6
Total	384	56	210	24		137	21		31	8		6	3	

Short or long *duration of postoperative hospitalization* did not show any significant difference when correlated with the frequency of osteoarthritis.

141 persons had had *athletic activities after operation*, or 32.0 per cent of the totally meniscectomized patients. None of these cases belonged to group III, and only 4 to group II. That postoperative sport could have a prophylactic effect on the occurrence of *osteoarthritis is improbable*; it

[3]—[4]) The results obtained from the analysis of the roentgenologic findings based on the evaluation of the second radiologist showed no significant difference in the frequency of roentgenologic signs of osteoarthritis between a) patients treated with or without postoperative fixation, and b) patients who were allowed weight bearing earlier or later than 2 weeks

is more likely that patients with degenerative arthritis refrained from sport after the operation. Scheibe (1963) pointed out, however, that athletic activities after operation do not appear to increase the frequency of osteoarthritis in meniscectomized knees.

The *type of occupation engaged in after operation* might conceivably be of importance for the occurrence of roentgenologic arthritis; work causing more knee strain would be liable to result in a higher frequency of osteoarthritis. On the whole, however, there is no significant difference between the various occupational groups in this material with regard to the frequency of degenerative arthritis.

According to Aarstrand (1954), the mean age of patients with roentgenologic signs of osteoarthritis at the follow-up examination was higher than that of patients without such findings.

As shown in table 22 the highest frequency of osteoarthritis occurred among patients who were at least 61 years old at the time of the follow-up investigation. The difference in the frequency of osteoarthritis compared with that of age groups under 61 at the follow-up is highly significant ($X^2 = 19.24^{***}$ d. f. = 4). If, besides *age at the follow-up investigation* also the length of the observation period is taken into consideration, the same high frequency of osteoarthritis will be found for patients over 61 years old and with a short observation period between 4—13 years. This difference is also highly significant ($X^2 = 19.45^{***}$ d. f. = 4). The significantly higher frequency of osteoarthritis in the oldest group of followed-up patients appears to be connected with the demonstrated higher frequency of degenerative arthritis for patients operated after 41 years of age.

A comparison has also been made between the operated and the non-operated knee in respect of the frequency of degenerative arthritis in the

TABLE 22 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis in respect of the patient's age at the follow-up* *M = males, F = females % = M + F*

Age at follow-up	Total Number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
	M	F	M	F		M	F		M	F		M	F	
Under 41 years	118	19	72	13	62.0	39	5	32.1	7	1	5.9	0	0	0
41—60 „	212	25	117	11	54.0	73	9	34.6	19	4	9.7	3	1	1.7
Over 61 „	54	12	21	0	31.8	25	7	48.5	5	3	12.1	3	2	7.6
Total	384	56	210	24		137	21		31	8		6	3	

various age groups at the follow-up. A significantly higher frequency of osteoarthritis is found in the operated knee in all age groups; in the age group under 41 years ($X^2 = 60.86$*** d. f. = 2), in the group 41—60 years ($X^2 = 124.43$*** d. f. = 2) and in the group over 61 years ($X^2 = 46.08$*** d. f. = 2).

f. SUMMARY OF ROENTGENOLOGIC RESULTS

Roentgenologic osteoarthritis following meniscectomy has proved to be significantly more frequent in the operated knee than in the nonoperated knee.

On the whole it has not been possible to establish any significant difference between medially and laterally meniscectomized knees. In agreement with Franke (1966) a significantly higher frequency of roentgenologic osteoarthritis was found in this material too in women as compared with men.

Scheibe (1963) and Herschmann (1965) among others consider that preferably patients over 40—45 years should not be operated, because of the risk of osteoarthritis, developing in the operated knee as a result of the intervention, being greater in older patients than in younger. In this material it was also found that the frequency of osteoarthritis was higher in the operated knees of patients meniscectomized when they were over 41 years old compared with those operated before they were 41. The differences are almost significant for total meniscectomies in the entire material (X^2 = *), for medially meniscectomized knees (X^2 = *), and for men (X^2 = *) [5] The differences for laterally meniscectomized knees and for women were not statistically significant.

It has been maintained that a long latency period causes an increase in the frequency of degenerative arthritis in a meniscectomized knee (Nitter 1946, Barfod & Bierring 1956, Scheibe 1963, Franke 1966, Mohing 1966). This material has not shown any significant connection between a longer latency period and a higher frequency of osteoarthritis in the meniscectomized knees; this is in agreement with the observations of other authors (Saugmann-Jensen 1963, Allegreni & Dell'Orto 1965, Jackson 1968, Tapper & Hoover 1969)

[5]) see footnote page 32

The importance of an initial trauma for the development of degenerative arthritis following meniscectomy has been pointed out earlier (Fuss 1951, Tapper & Hoover 1969). In the present material no statistically significant difference has been found, between the patients operated for traumatic and nontraumatic injuries of the semilunar cartilage, with regard to the frequency of roentgenologic osteoarthritis in the meniscectomized knee.

It has been asserted that the length of the observation period is of importance for the frequency of roentgenologic osteoarthritis. Consequently several authors have pointed out that a material can be regarded as representative only if the observation period is sufficiently long (Nitter 1946, Streli 1955, Saugmann-Jensen 1963, Allegreni & Dell'Orto 1965, Mohing 1966, Jackson 1968). In this material an increasing frequency of degenerative arthritis has been found for longer observation periods than 24 years compared with shorter. In this respect the obtained differences are almost significant for the entire material of total meniscectomies (X^2 = *), for medially meniscectomized knees alone (X^2 = *), and highly significant for men alone (X^2 = ***).

Among other factors which possibly provoke osteoarthritis, preoperative symptoms — lockings, effusion, haemarthrosis or a combination of these — and postoperative complications have not been found to affect the frequency of roentgenologic osteoarthritis in a significant way. Correlation of the frequency of roentgenologic osteoarthritis with postoperative muscular training, duration of hospitalization, sport after operation, or effect on the knee of type of occupation did not give significant differences. On the other hand, a significantly higher frequency of degenerative arthritis at the follow-up examination was found in knees in which roentgenologic signs of osteoarthritis existed already prior to operation (X^2 = ***), if osteoarthritis was diagnosed at operation (X^2 = ***), if fixation was applied postoperatively (X^2 = *) [6], when weight bearing on the operated knee was allowed first after 2 weeks (X^2 = *) [7], and in patients of advanced age at the follow-up investigation in spite of shorter observation periods (X^2 = ***). Also by comparing the operated and the non-operated knee a higher degree of osteoarthritis was found in patients of advanced age at follow-up as compared with younger patients (X^2 = ***).

[6]—[7]) see footnote page 41

2. SUBJECTIVE COMPLAINTS

The reported frequency of different subjective complaints varies largely according to different authors (table 23). These variations are probably due to the different methods applied in collecting data. Some authors base their conclusions solely on answers to questionnaires sent to the subject (Strahlmann & White 1921, MacAusland 1931, Meier 1933, Sjövall 1942, Perey 1962). Other authors rely their reports partly on questionnaires and partly on interrogation at personal investigations (Lagergren 1953, Kühnel 1964, Huckell 1965). Some authors base their results exclusively on interrogation at the follow-up investigation (Birgfeld 1928, Aleman & Friberg 1934, Saugmann-Jensen 1963, Franke 1966).

Franke (1966) stated that 75.2 per cent of the patients with roentgenologic changes were subjectively entirely free from symptoms. Jackson (1968) also pointed out that there was not always agreement between roentgenologic signs of degenerative arthritis and subjective complaints.

Sjövall (1942) reported that in his material 44 per cent of the patients complained of weakness in the operated knee.

TABLE 23 *The frequency of subjective complaints in different groups according to different authors*

<table>
<tr><th>Authors</th><th>Number of cases</th><th>Excellent %</th><th>Good %</th><th>Fair %</th><th>Bad %</th></tr>
<tr><td>Strahlman & White (1921)</td><td>50</td><td colspan="2">86.0</td><td colspan="2">14.0</td></tr>
<tr><td>Birgfeld (1928)</td><td>68</td><td>79.4</td><td>16.2</td><td>2.9</td><td>1.5</td></tr>
<tr><td>MacAusland (1931)</td><td>287</td><td>80.1</td><td>9.8</td><td colspan="2">10.1</td></tr>
<tr><td>Meier (1933)</td><td>146</td><td>68.5</td><td>31.5</td><td>0</td><td>0</td></tr>
<tr><td>Aleman & Friberg (1934)</td><td>186</td><td>85.5</td><td></td><td></td><td></td></tr>
<tr><td>Sjövall (1942)</td><td>140</td><td>20.1</td><td>51.4</td><td>26.4</td><td>2.1</td></tr>
<tr><td>Lagergren (1953)</td><td>97</td><td>64.0</td><td>21.0</td><td>10.0</td><td>5.0</td></tr>
<tr><td>Perey (1962)</td><td>33</td><td>70.0</td><td>15.0</td><td></td><td></td></tr>
<tr><td>Saugmann-Jensen (1965)</td><td>93</td><td>61.3</td><td>25.8</td><td>7.5</td><td>5.4</td></tr>
<tr><td>Monn (1964)</td><td>52</td><td>56.0</td><td>19.0</td><td colspan="2">25.0</td></tr>
<tr><td>Kühnel (1964)</td><td>326</td><td>79.8</td><td>15.3</td><td colspan="2">4.9</td></tr>
<tr><td>Huckell (1965)</td><td>64</td><td>40.0</td><td>24.0</td><td>20.0</td><td>16.0</td></tr>
<tr><td>Franke (1966)</td><td>98</td><td>41.9</td><td>36.7</td><td>16.3</td><td>5.1</td></tr>
<tr><td>Appel (1970)</td><td>440</td><td>62.3</td><td>29.1</td><td>7.5</td><td>1.1</td></tr>
</table>

Own investigations

As was mentioned in the chapter on Methods, a standardized form was used to record subjective complaints reported by the patient. The frequency of these complaints, regardless of their degree, is shown in table 24. The two most frequent complaints were pain on weight bearing and a feeling of weakness in the knee. The frequency of pain on weight bearing was significantly higher in females ($X^2 = 21.39^{**}$ d. f. = 1) than in males. There was no significant difference between medially operated and laterally operated knees with regard to pain on weight bearing.

TABLE 24. *The frequency of different subjective complaints in patients after total meniscectomy.*

Subjective complaints	Medial		Lateral	
	Males	Females	Males	Females
Pain at rest	14	5	2	2
Pain on weight bearing	66	22	16	6
Weakness feeling	63	15	16	3
Walking disability	32	14	7	0
Lockings	3	3	2	0
Other complaints	15	1	5	0

Feeling of weakness in the operated knee did not show any significant difference between medially and laterally operated knees, nor when men and women were compared in this respect.

Difficulty in going upstairs or uphill occurred also comparatively often and the frequency was significantly higher for women than for men ($X^2 = 10.16^{**}$ d. f. = 1). No significant difference was established between medially and laterally meniscectomized knees.

Each patient might have no complaints or some or all of those included in the form. Each individual complaint was graded with symbols 1+, 2+ or 3+ according to the intensity mentioned by the patient. Thus, for example, a patient could complain of moderate pains on weight bearing (1+) and pronounced difficulty in going upstairs (2+) and at the same time also slight swelling (1+). This patient was given a *total grading of 4+*. Another patient complained, for example, of mild pain on weight bearing (1+) and moderate feeling of weakness in the knee (1+) and was given a *total of 2+*. A patient was placed with regard to the total score of + he acquired, in one of the four groups for subjective complaints i. e., *Excellent:* symptom-free; *Good:* 1+ or 2+; *Fair* 3+ or

4+ and *Bad:* 5+ or more. However a few patients stating several complaints of slight degree, were allocated to either group *Good* or *Fair* according to the general impression given by the described intensity of their combined complaints.

In respect of subjective complaint, the material consisting of total meniscectomies was divided according to the above principles, as shown in table 25.

TABLE 25 *Distribution of totally meniscectomized knees in different groups of subjective complaints M = males, F = females % = M + F*

Operated meniscus	Total number		Excellent Number		%	Good Number		%	Fair Number		%	Bad Number		%
	M	F	M	F		M	F		M	F		M	F	
Medial	327	44	219	18	63.9	88	15	27.7	16	10	7.0	4	1	1.4
Lateral	57	12	32	5	53.6	18	7	36.3	7	0	10.1	0	0	0
Total	384	56	251	23	62.3	106	22	29.1	23	10	7.5	4	1	1.1

If subjective complaints are correlated with the roentgenologic findings it is obvious that there is not always an agreement between them (table 26).

TABLE 26. *Distribution of totally meniscectomized knees in different groups of subjective complaints correlated with the distribution by different roentgenologic groups of osteoarthritis M = males, F = females*

Roentgenologic findings	Total		Subjective complaints Excellent		Good		Fair		Bad	
	M	F	M	F	M	F	M	F	M	F
Group 0	210	24	152	9	50	11	8	4	0	0
Group I	137	21	89	10	38	8	10	3	0	0
Group II	31	8	10	3	14	3	4	1	3	1
Group III	6	3	0	1	4	0	1	2	1	0
Total	384	56	251	23	106	22	23	10	4	1

If the occurrence of clear-cut subjective complaints of group *Fair* and group *Bad* is compared between women and men, the total subjective complaints show a significantly higher frequency for women ($X^2 = 15.92^{***}$ d.f. = 2). On the other hand, there is no significant difference between medially and laterally meniscectomized knees.

Comments

The present material shows a lower frequency of cases with clear-cut subjective complaints of groups Fair and Bad compared with the reports of other authors (table 23). Aleman & Friberg (1934) reported higher frequency of *Excellent* and *Good* results, without giving an account, however, of their bad results. Perey (1962) had a lower percentage of cases belonging to groups *Excellent* and *Good* and MacAusland (1931) a higher percentage belonging to groups *Fair* and *Bad*.

The present material shows a significantly higher frequency of subjective complaints for women than for men. There were no significant differences between medially and laterally meniscectomized knees.

As was also reported by Franke (1966) and Jackson (1968) in many cases here the degree of roentgenologic findings of osteoarthritis and the subjective complaints were not always in agreement.

In order to shed more light on the effect of the different factors on the subjective complaints, this has been analyzed in the same way as the roentgenologic findings.

a. AGE AT TIME OF OPERATION

Earlier reports maintain that the frequency of subjective complaints following meniscectomy is lower in younger than in older patients (Mac Ausland 1931, Saugmann-Jensen 1963). Lower frequency of subjective complaints has also been reported for elderly patients at the time of operation (Meier 1933). Some authors have maintained that nothing definite can be stated concerning the importance of age at operation for the occurrence of subjective complaints (Lagergren 1953, Monn 1964, Huckell 1965).

Own investigations

When the subjective complaints in this material are correlated with age at operation, for patients over and under 41 years, there are only small differences in the frequency of subjective complaints (table 27). These differences are not statistically significant.

Comments

Correlation between subjective complaints and age at operation does not show in the present material any statistically significant differences as regards the frequency for subjective complaints of the groups *Fair* and *Bad* in patients operated either before or after 41 years of age. These results point in the same direction as the results of several other authors, who consider that age at operation is of no importance for the occurrence of subjective complaints (Lagergren 1953, Monn 1964, Huckell 1965).

TABLE 27 *Distribution of totally meniscectomized knees in different groups of subjective complaints correlated with age at operation. M = males, F = females % = M + F*

Age at operation	Total Number		Excellent Number		%	Good Number		%	Fair Number		%	Bad Number		%
	M	F	M	F		M	F		M	F		M	F	
Under 21 years	44	8	29	2		10	5		4	1		1	0	
21—30 "	144	12	87	3		46	8		10	1		1	0	
31—40 "	102	10	74	5		23	3		4	1		1	1	
Under 41 years	290	30	190	10	62.5	79	16	29.7	18	3	6.6	3	1	1.2
41—50 years	60	17	39	9		19	3		2	5		0	0	
51—60 "	32	8	21	4		7	2		3	2		1	0	
Over 61 "	2	1	1	0		1	1		0	0		0	0	
Over 41 years	94	26	61	13	61.7	27	6	27.5	5	7	10.0	1	0	0.8

b. LATENCY PERIOD

Several earlier authors consider the risk of increased frequency of subjective complaints following meniscectomy to be greater with longer latency period and, consequently, they recommend that operation should be performed as early as possible (Strahlman & White 1921, Birgfeld 1928, MacAusland 1931, Saugmann-Jensen 1963, Kuhnel 1964, Huckell 1965). However, there are also authors who did not observe any correlation between subjective complaints and long latency period (Sjovall 1942, Monn 1964).

Own investigations

Table 28 and fig. 10 show the distribution of the material when subjective complaints are correlated with latency periods shorter and longer than 6 months. In total meniscectomies a higher frequency of knees, causing subjective complaints of the groups *Fair* and *Bad*, was observed among patients who were operated with a latency period of less than 6 months compared with knees operated after 6 months, but the difference is not statistically significant. No significant differences in the frequency of subjective complaints in respect of the latency period were observed for either medially or laterally meniscectomized knees or separately for men and women.

Nor has the length of the latency period any effect on the subjective complaints when correlating these with latency periods longer or shorter than 6 months in patients under or over 41 years at the time of operation.

Comments

In the present material no statistically significant differences in the frequency of subjective complaints were established for knees operated after latency periods longer or shorter than 6 months. These results are thus in agreement with the view that the length of the latency period is of no importance for the occurrence of subjective complaints (Sjovall 1942, Monn 1964).

TABLE 28 *Distribution of totally meniscectomized knees in different groups of subjective complaints correlated with the latency period M = males, F = females. % = M + F*

Operated meniscus	Latency period	Total Number		Excellent Number		%	Good Number		%	Fair Number		%	Bad Number		%
		M	F	M	F		M	F		M	F		M	F	
Medial	Under 6 months	177	28	120	13	64.9	46	8	26.3	11	6	8.3	0	1	0.5
Lateral	Under 6 months	27	2	14	2	55.2	9	0	31.0	4	0	13.8	0	0	0
Total under 6 months		204	30	134	15	63.7	55	8	26.9	15	6	9.0	0	1	0.4
Medial	Over 6 months	150	16	99	5	62.7	42	7	29.5	5	4	5.4	4	0	2.4
Lateral	Over 6 months	30	10	18	3	52.5	9	7	40.0	3	0	7.5	0	0	0
Total over 6 months		180	26	117	8	60.7	51	14	31.6	8	4	5.8	4	0	1.9

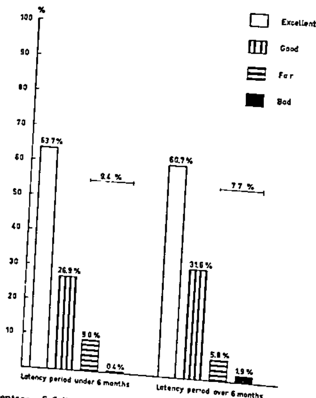


FIG 10 Percentage of followed-up meniscectomized patients distributed by different groups of subjective complaints and latency periods Percentage of groups Fair and Bad given together at the top

c. TYPE OF TRAUMA

There are only a few authors who correlate the type of trauma or its absence with subjective complaints alone. It may be mentioned, however, that MacAusland (1931) stated that even slight traumata are important for the degree of subjective complaints after meniscectomy, while Tapper & Hoover (1969) consider that a more pronounced trauma may be the cause of increased subjective complaints.

Own investigations

When the total meniscectomies are divided into definitely traumatic and nontraumatic cases, and these two groups are then correlated with the

different groups of subjective complaints, the distribution shown in table 29 is obtained. Investigation of the relation between traumatic and non-traumatic injuries of the semilunar cartilage and the frequency of subjective complaints of the groups *Fair* and *Bad* after meniscectomy did not shows any significant differences.

Comments

In the present material there was no significant difference with regard to the subjective complaints, between knees meniscectomized because of traumatic and nontraumatic *injuries of the semilunar cartilage* respectively. This conflicts with the view held by other authors (MacAusland 1931, Tapper & Hoover 1969).

TABLE 29. *Distribution of totally meniscectomized knees in different groups of subjective complaints correlated with the factor trauma.*
M = males, F = females. % = M + Γ

Operated meniscus	Factor trauma	Total Number		Excellent Number		Excellent %	Good Number		Good %	Fair Number		Fair %	Bad Number		Bad %
		M	F	M	F		M	F		M	F		M	F	
Medial	traumatic	279	36	190	16	49.3	73	13	40.0	12	6	8 4	4	1	2 3
Lateral	„	36	5	18	2	48 8	12	3	36.6	6	0	14.6	0	0	0
Total	traumatic	315	41	208	18	63 5	85	16	28 4	18	6	6.7	4	1	1 4
Medial	nontraumatic	48	8	29	2	55.4	15	2	30 4	4	4	14 2	0	0	0
Lateral	„	21	7	14	3	60.7	6	4	35 7	1	0	3.6	0	0	0
Total	nontraumatic	69	15	43	5	57.2	21	6	32 1	5	4	10 7	0	0	0

TABLE 30 *Distribution of totally meniscectomized knees in different groups of subjective complaints correlated with the observation period in decades*
M = males, F = females. % = M + F

Observation period	Total Number		Excellent Number		Excellent %	Good Number		Good %	Fair Number		Fair %	Bad Number		Bad %
	M	F	M	F		M	F		M	F		M	F	
4—13 years	219	44	140	17	59 7	62	18	30 4	15	8	8 8	2	1	1 1
14—23 „	106	8	66	4	61 4	32	2	29 8	6	2	7 0	2	0	1 8
24—33 „	53	4	40	2	73 7	11	2	22 8	2	0	3 5	0	0	0
34—43 „	6	0	5	0	83 3	1	0	16 7	0	0	0	0	0	0
Total	384	56	251	23		106	22		23	10		4	1	

d. OBSERVATION PERIOD

Unanimity in assessing the importance of the length of the observation period in relation to subjective complaints is striking. No author has reported an increase in subjective complaints after a longer observation period. Most authors do not report any difference in this respect between cases with longer and shorter observation periods (Meier 1933, Sjovall 1942, Petey 1962, Tapper & Hoover 1969), while a decrease in subjective complaints after a longer observation period has also been reported (Monn 1964).

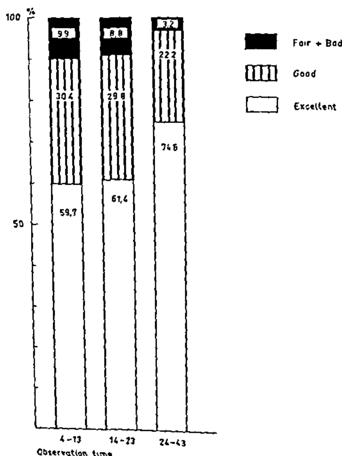


FIG 11 Percentage frequencies of the different groups of subjective complaints according to observation period in decades

Own investigations

Table 30 shows the subjective complaints after meniscectomy correlated with the observation time divided into 10-years periods. The frequency of subjective complaints of groups *Fair* and *Bad* decreased slightly with increasing observation periods (fig. 11). The differences are not significant.

Comments

In contrast to a significantly increased frequency of roentgenologic signs of osteoarthritis with an increasing observation period, there was a slight, though not significant decrease in the frequency of subjective complaints of groups *Fair* and *Bad*. This is in agreement with the conception of other authors regarding the influence of the observation period on subjective complaints (Meier 1933, Sjövall 1943, Percy 1962, Tapper & Hoover 1969).

e. OTHER FACTORS WHICH POSSIBLY PROVOKE SUBJECTIVE COMPLAINTS

A comparison between meniscectomized knees with and without *preoperative clinical findings*, such as lockings, effusion etc. did not show any significant differences in respect of subjective complaints.

When comparing meniscectomized knees with and without *osteoarthritis diagnosed prior to or at operation*, there was no significant difference as regards the frequency of subjective complaints at the follow-up. *Other findings at operation*, such as osteochondritis, ligament injuries etc. occurred in so few cases that no analysis of these was possible.

No *postoperative complications* had occurred in any of the patients belonging to the group *Bad*. Nor did any patient in the group *Fair* display postoperative infection; but in this group there had been three cases of persisting effusion and two patients had had haemarthrosis. No statistically significant differences were observed in the frequencies of the subjective complaints when comparing knees separately with and without either of these postoperative complications after meniscectomy.

Meniscectomized knees in patients with and without *postoperative muscular training* did not show any significant differences on correlation with frequency of subjective complaints of groups *Fair* and *Bad*. The same applies also when comparing operated knees with and without *postoperative fixation*.

Meniscectomized knees where *weight bearing* was allowed first 2 weeks postoperatively showed an almost significant higher frequency of subjective complaints, when compared with knees where weight bearing was allowed earlier ($X^2 = 10.08^*$ d. f. = 4) (table 31).

Patients hospitalized for longer than 2 weeks after the operation showed a higher frequency of subjective complaints compared with those with a shorter *hospitalization* ($X^2 = 6.36^*$ d. f. = 2) (table 32).

No patient in the group *Bad* had practised any kind of *sport* after operation; only five in the group *Fair* had done so.

The *type of occupation after operation* had no significant influence on the frequency of subjective complaints.

With regard to the subjective complaints, *age at the follow-up investigation* does not seem to play the same role as for the roentgenologic findings. No significant differences were found between various age groups when these were correlated with the degree of subjective complaints.

TABLE 31 *Distribution of totally meniscectomized knees in different groups of subjective complaints correlated with the time when weight bearing was first allowed after operation M = males, F = females. % = M + F.*

Postoperative weight bearing allowed	Total Number M	F	Excellent Number M	F	%	Good Number M	F	%	Fair Number M	F	%	Bad Number M	F	%
Within 1 week	40	2	23	1	57 1	13	1	33 3	4	0	9 6	9	0	0
„ 8—14 days	258	31	174	12	64 3	71	15	29.7	11	4	5 2	2	0	0 8
After 2 weeks	86	23	54	10	58 7	22	6	25 7	8	6	12 8	2	1	2.8
Total	384	56	251	10		106	22		23	10		4	1	

TABLE 32 *Distribution of the degree of subjective complaints in totally meniscectomized knees correlated with length of postoperative hospitalization M — males, F = females % = M + F*

Length of postoperative hospitalization	Total Number M	F	Excellent Number M	F	%	Good Number M	F	%	Fair Number M	F	%	Bad Number M	F	%
1 week	5	0	3	0	60 0	2	0	40 0	0	0	0	0	0	0
8—14 days	180	19	111	7	59 3	59	9	34 2	8	3	5.5	2	0	1 0
Over 2 weeks	199	37	137	16	64.9	45	13	24 6	15	7	9 3	2	1	1 2
Total	384	56	251	23		106	22		23	10		4	1	

f. SUMMARY OF SUBJECTIVE COMPLAINTS

On the whole, subjective complaints observed in the present material were of the same order of size as that reported by earlier authors (Mac Ausland 1931, Aleman & Friberg 1934, Percy 1962).

In several respects women were found to have a higher frequency of subjective complaints than men (X^2 = ** to ***).

Lower frequencies of subjective complaints for patients who were younger at operation had been reported earlier (MacAusland 1931, Saugmann-Jensen 1963). This conception has not been verified in this material. Thus, with regard to subjective complaints, no significant differences between patients operated before or after 41 year of age were found. This supports the view that the age at the time of operation does not influence the occurrence of subjective complaints (Lagergren 1953, Monn 1964, Huckell 1965).

The length of the latency period has not been found to influence significantly the frequency of subjective complaints. This corresponds with the statements of Sjövall (1942) and Monn (1964) among other investigators.

Trauma or its absence in connection with injury of the semilunar cartilage could not be significantly linked with the occurrence of subjective complaints after operation. This observation disagrees with the assertion made by MacAusland (1931) and Tapper & Hoover (1969), that an initial trauma gives rise to higher frequency of subjective complaints following meniscectomy.

The frequency of subjective complaints with regard to the length of the observation period showed no significant differences, which corresponds with earlier reported observations. (Meier 1933, Sjovall 1942, Percy 1962, Tapper & Hoover 1969).

Weight bearing at a later stage after the operation and longer hospitalization time have shown a significantly higher frequency of subjective complaints (X^2 = *).

3. OBJECTIVE CLINICAL FINDINGS

In reports concerning follow-up investigations of meniscectomized patients, thorough analysis of registered objective symptoms, such as decreased range of motion, loss of strength, and muscular atrophy is more or less neglected. Subjective complaints are sometime added to descriptions of the local status as reported by the patient in follow-up investigations based on questionnaires, or objective findings, subjective complaints and roentgenologic findings are all added together in the evaluation of the results of follow-up investigations performed personally by the author. Normal findings in respect especially of objective symptoms have been reported to vary between 40 and 70 per cent (Efskind 1939, Saugmann-Jensen 1963).

Own investigations

As stated in the chapter on "Methods", the objective symptoms observed at the follow-up examination were recorded on the standardized scheme 1 and the results of the comparison of the findings between the operated and the nonoperated knee were transferred to scheme 2. The frequency of the various objective symptoms is demonstrated in table 33. In this connection it should be pointed out that several objective symptoms may have been observed in the same patient.

TABLE 33 *The frequency of various objective findings at the follow-up in totally meniscectomized patients The operated knee is compared with the non-operated*

	Medial		Lateral		Total	%
	Males	Females	Males	Females		
Increased skin temp	0	1	0	0	1	
Soft tissue swelling	6	13	2	1	22	5 0
Hypertrophied 'Hoffa'	1	2	0	0	3	
Capsule thickening	11	12	5	2	30	6 8
Effusion	3	0	0	0	3	
Tenderness medially op knee	54	14	3	1	72	16 4
" laterally op knee	7	2	5	0	14	3 2
Other localisation of tenderness op knee	2	3	0	1	6	1 4
Moderate crepitation	206	29	38	5	278	63 2
Pronounced "	22	6	3	3	34	7 7
Lateral instability	7	1	0	0	8	1 8
Cruciate ligament instability	0	0	0	0	0	

Table 33 (continued)

	Medial		Lateral		Total	%
	Males	Females	Males	Females		
Decreased range of active extension (up to 10°)	8	4	1	0	13	2 9
Decreased range of active extension (more than 10°)	0	0	0	1	1	
Decreased range of active flexion (up to 10°)	20	3	7	1	31	7.0
Decreased range of active flexion (more than 10°)	9	6	6	0	21	4.8
Decreased muscular strength (more than 10°)	39	6	10	2	57	12.9
Quadriceps atrophy (more than 2 cm)	8	1	2	0	11	2.5

The most usual objective symptoms after meniscectomy in the present series were crepitation which occurred in more than 70 per cent of the patients. Tenderness on palpation of the medial side of medially as well as laterally meniscectomized knees was present in 16.4 per cent. Restricted active flexion occurred in 11.8 per cent, whereas 12.9 per cent of the patients had reduced muscular strength in the operated knee as compared with the nonoperated; decreased range of extension up to 10° in the operated knee compared with the nonoperated knee was present in 7.0 per cent of the cases.

Because of the relatively low *frequency of clinical objective symptoms* the material has been divided only into two groups when summing up these findings.

Normal group: To this group have been allocated not only patients without objective symptoms but also cases with a slight degree of a single objective finding, such as crepitations, *reduced muscular strength, muscular* atrophy or restriction of active flexion less than 10°.

Group with objective findings: All knees with more than one, or one pronounced objective finding, were assigned to this group.

The results, obtained on dividing the patients according to the above-mentioned principles, are shown i table 34. As seen in the table, a higher frequency of objective findings was present in laterally than medially meniscectomized knees, but the difference is not significant. A higher frequency of objective findings was observed for the women compared with *the men, but this difference* was also not significant.

No obvious correlation exsisted between objective findings and roent-

genologic signs of osteoarthritis or subjective complaints (tables 35 and 35 a).

The same analysis, as that done for the roentgenological findings and the subjective complaints, will be attempted in the following, in respect of the possible influence of different factors on the occurrence of objective clinical findings.

TABLE 34 *Totally meniscectomized knees distributed according to the absence or presence of objective findings at the follow-up M = males, F = females %= M + F*

Operated meniscus	Total Number		Normal Number		%	With findings Number		%
	M	F	M	F		M	F	
Medial	327	44	270	33	81 7	57	11	18.3
Lateral	57	12	40	10	72 5	17	2	27 5
Total	384	56	310	43	80 2	74	13	19 8

TABLE 35 *Roentgenologic signs of osteoarthritis correlated with the objective findings at the follow-up in totally meniscectomized patients M = males, F = females*

Objective findings	Total		Roentgenologic findings Group 0		Group I		Group II		Group III	
	M	F	M	F	M	F	M	F	M	F
Normal	310	43	183	21	107	17	19	4	1	1
With findings	74	13	27	3	30	4	12	4	5	2
Total	384	56	210	24	137	21	31	8	6	3

TABLE 35 a *Objective findings at follow-up correlated with the degree of subjective complaints in totally meniscectomized patients M = males, F = females*

Objective findings	Total		Subjective complaints Excellent		Good		Fair		Bad	
	M	F	M	F	M	F	M	F	M	F
Normal	310	43	223	19	76	20	10	4	1	0
With findings	74	13	28	4	30	2	13	6	3	1
Total	384	56	251	23	106	22	23	10	4	1

a. AGE AT TIME OF OPERATION

In the entire material of totally meniscectomized knees objective findings correlated with age at operation, with a borderline at 41 years of age (table 36) are more frequent in patients operated after than before 41 years of age, the difference being highly significant ($X^2 = 16.80^{***}$ d. f. = 1). Similarly there was also a highly significant increase in objective findings in medially meniscectomized patients who were over 41 years when operated on compared with those under 41 at operation ($X^2 = 18.20^{***}$ d. f. = 1). The difference observed in laterally meniscectomized knees was not significant. Men and women separately showed also higher frequency of objective findings when meniscectomy was performed on patients over 41 years. The differences are significant for both men ($X^2 = 8.84^{**}$ d. f. = 1) and women ($X^2 = 9.93^{**}$ d. f. = 1).

TABLE 36. *Objective findings at follow-up correlated with age at operation in totally meniscectomized patients M = males, F = females. % = M + F*

Operated *meniscus*	Age at *operation*	Total *Number* M	F	Normal *Number* M	F	%	With findings *Number* M	F	%
Medial	Under 41 years	241	23	209	21	87.1	32	2	12.9
Lateral	„ 41 „	49	7	35	7	75.0	14	0	25.0
Total	under 41 years	290	30	244	28	85.0	46	2	15.0
Medial	Over 41 years	86	21	61	12	68.2	25	9	31.8
Lateral	„ 41 „	8	5	5	3	61.5	3	2	38.5
Total	over 41 years	94	26	66	15	67.5	28	11	32.5

b. LATENCY PERIOD

When correlating the latency period with the objective findings no great differences are found for patients operated after a latency period under or over 6 months (table 37). Throughout, the differences are not statistically significant.

Correlation of the objective symptoms, on the one hand, with the length of the latency period, and, on the other, with the age at operation, gave no significant differences for latency periods under or over 6 months, either for patients under 41 or for those over 41 years at operation.

TABLE 37 *Objective findings at follow-up correlated with the latency period in totally meniscectomized patients M = males, F = females % = M + F.*

Operated meniscus	Latency period	Total Number M	F	Normal Number M	F	%	With findings Number M	F	%
Medial	Under 6 months	177	28	150	21	83 4	27	7	16 6
Lateral	" 6 "	27	2	17	1	62 1	10	1	37.9
Total	Under 6 months	204	30	167	22	80 8	37	8	19 2
Medial	Over 6 months	150	16	120	12	79 5	30	4	20 5
Lateral	" 6 "	30	10	23	9	80 0	7	1	20 0
Total	over 6 months	180	26	143	21	79 6	37	5	20 4

c. TYPE OF TRAUMA

When the objective findings are correlated with the factor preoperative trauma, no statistically significant differences are found in separate analyses for the entire material of total meniscectomies, for medial meniscectomies, for lateral meniscectomies, and for men and for women (table 38).

TABLE 38 *Objective findings at follow-up correlated with the factor trauma in totally meniscectomized patients M = males, F = females % = M + F.*

Operated meniscus	Factor trauma	Total Number M	F	Normal Number M	F	%	With findings Number M	F	%
Medial	traumatic	279	36	230	28	81 9	49	8	18 1
Lateral	"	36	5	24	3	65.9	12	2	34 1
Total	traumatic	315	41	254	31	80 1	61	10	19 9
Medial	nontraumatic	48	8	40	5	80 4	8	3	19 6
Lateral	"	21	7	16	7	82 1	5	0	17.9
Total	nontraumatic	69	15	56	12	81 0	13	3	19 0

d. LENGTH OF OBSERVATION PERIOD

Table 39 shows the distribution for the entire material when correlating the groups of objective findings with the groups of different observation periods. Existing differences are not statistically significant. This applies to the entire material, to medially operated, to laterally operated knees, and to men and women taken separately.

TABLE 39. *Objective findings at follow-up correlated with the length of observation period in totally meniscectomized patients. M = males, F = females. % = M + F.*

Period of observation	Total Number		Normal Number		Normal %	With findings Number		With findings %
	M	F	M	F		M	F	
4—13 years	219	44	176	35	80 2	43	9	19 8
14—23 „	106	8	87	6	81.6	19	2	18 4
24—33 „	53	4	42	2	77 2	11	2	22.8
34—43 „	6	0	5	0	83 3	1	0	16 7
Total	384	56	310	43	80 2	74	13	19 8

e. OTHER FACTORS POSSIBLY CONNECTED WITH THE DEVELOPMENT OF POSTOPERATIVE OBJECTIVE FINDINGS

Preoperative clinical findings did not show any significant influence on the occurrence of objective symptoms postoperatively.

Secondary findings at operation — with the exception of osteoarthritis — could not be analyzed statistically on account of the few cases recorded. Knees with signs of osteoarthritis diagnosed at operation showed, compared with knees without osteoarthritis at operation, an almost significantly higher frequency of objective findings at the follow-up investigation ($X^2 = 5.38$, d. f. = 1).

Postoperative complications did not show any significant influence on the objective symptoms.

Nor was *postoperative muscular training* found to influence the objective symptoms significantly.

Knees treated with *postoperative fixation* showed a higher frequency

of objective findings compared with operated knees without postoperative fixation. The difference was almost significant ($X^2 = 4.04^*$ d. f. = 1).

An almost significant increase in the frequency of objective findings was observed in patients with later start with *postoperative weight bearing* compared with patients who were allowed weight bearing earlier ($X^2 = 8.56^*$ d. f. = 2).

Patients with longer *postoperative hospitalization* showed a significantly higher frequency of objective findings compared with those with shorter hospitalization ($X^2 = 10.25^{**}$ d. f. = 1).

Sport after operation did not influence significantly the frequency of objective symptoms.

The *type of occupation* did not seem to have any significant importance for the occurrence of objective symptoms in the meniscectomized knee.

TABLE 40 *Objective findings correlated with age at follow-up in totally meniscectomized patients M = males, F = females % = M + F*

Age at Follow-up	Total Number		Normal Number		%	With findings Number		%
	M	F	M	F		M	F	
Under 41 years	118	19	98	18	84 9	20	1	15 1
41–60 "	212	25	178	19	83 1	34	6	16 9
Over 61 "	54	12	34	6	60 6	20	6	39 4
Total	384	56	310	43		74	13	

Age at the follow-up investigation correlated with the objective symptoms showed a higher frequency of objective findings in patients over 61 at the time of the follow-up, compared with younger patients (table 40). The observed difference is highly significant ($X^2 = 19.20^{***}$ d. f. = 2). On further correlation with the length of the observation period a highly significant increase in the frequency of objective findings was found in the group with the shortest observation period among older than in younger patients at the time of the follow-up ($X^2 = 22.10^{***}$ d. f. = 2). Thus, the high frequency of objective findings among older patients at the follow-up investigation seemed to be connected with the high frequency of objective findings among patients over 41 years at time of operation

f. SUMMARY OF OBJECTIVE SYMPTOMS

Very few authors have presented separately, objective findings present in meniscectomized knees during follow-up investigations.

In the present material the scanty occurrence of objective symptoms is striking. With regard to objective findings, there were no statistically significant differences between medially and laterally meniscectomized knees, nor between men and women.

The frequency of objective findings was higher for patients who were over 41 years at operation compared with those operated before they were 41. The difference is highly significant for the entire material of total meniscectomies (X^2 = ***), and for medially meniscectomized knees analysed separately (X^2 = ***), and significant for men (X^2 = **) and for women (X^2 = **) separately.

A latency period shorter or longer than 6 months did not influence the occurrence of objective findings significantly.

Nor did trauma, as aetiologic factor for the injury of the semilunar cartilage, influence the occurrence of objective symptoms significantly.

The length of the observation period did not seem to play any significant role in the occurrence of objective symptoms.

With regard to the other factors which might possibly affect the occurrence of objective findings, the following proved to influence the results significantly.

Signs of degenerative arthritis at operation were followed by an almost significant increase in the frequency of objective findings at the follow-up examination (X^2 = *). Postoperative fixation also showed an almost significant increase in the frequency of objective findings (X^2 = *) and so did late weight bearing (X^2 = *). A significant increase in objective findings was connected with a longer period of hospitalization (X^2 = **). A more advanced age at the time of the follow-up, in combination with a short observation period and, consequently, advanced age at time of operation showed a highly significant increase in the objective findings (X^2 = ***).

4. COMBINED TOTAL RESULTS

In several reports on follow-up investigations of meniscectomized series no account is given of the roentgenologic findings, subjective complaints or objective symptoms separately. Usually total results combining all three parameters are presented, and the patients are divided into 4 groups (table 41). The criteria for this classification, which can vary to some extent between the different authors, are discussed below in connection with the own classification. In some reports, in this respect the patients are divided for preference into 3 groups (table 42).

TABLE 41. *Combined total results of earlier reported series distributed in 4 different groups*

Authors	Total number	Excellent %	Good %	Fair %	Poor %	Type of oper.
Dengler (1938)	74	32 4	33 8	24 3	9 5	
Uebermuth (1941)	55	50 8	25 4	20 0	3 8	
Strels (1955)	82	74 4	24 4	1 2	0	partial
Scheibe (1963)	127	72 4	26 1	1 5	0	part + tot.
Leuschner & Weickert (1964)	91	57 1	31 9	11 0	0	"
Herschmann (1965)	163	69 7	20 0	9 1	1 2	total
Springorum (1966)	150	96 7	2 0	1 3	0	"
Tapper & Hoover (1969)	113	42 0	25 0	20 0	13 0	part + tot

TABLE 42 *Combined total results of earlier reported series distributed in 3 different groups*

Authors	Total number	Excellent %	Good %	Poor %
Raess (1930)	21	81 0	14 0	5 0
Spira (1933)	76	71 0	22 4	6 6
Meier (1933)	98	72 4	27 6	
Andersson (1934)	23	60 9	30 4	8 7
Brechling (1942)	45	78 0	11 0	11 0
Nitter (1946)	35	82 5	11 7	5 8
Barfod & Bierring (1956)	110	81 0	13 0	6 0

Reported results of follow-up investigations of meniscectomized patients are sometimes divergent

Thus, it has been stated that a higher frequency of unsatisfactory total results occurs in laterally than in medially meniscectomized knees (Ale-

man & Friberg 1934, Uebermuth 1941), but also that the frequency of satisfactory combined results is higher after lateral than after medial meniscectomies (Meier 1933).

Several authors have reported a distinctly higher frequency of unsatisfactory total results in women compared with men (Aleman & Friberg 1934, Brechling 1942, Lagergren 1953, Barfod & Bierring 1956, Tapper & Hoover 1969).

It has further been reported that "excellent" total results were observed in all 25 followed-up patients, who were over 60 years at the time of the operation (Litchman et al. 1966).

Own investigations

The main part of the present material, which comprises all totally meniscectomized knees, has been subjected to separate analyses of the roentgenologic findings, the subjective complaints, and the objective symptoms, and has also been analyzed in respect of different factors which might possibly cause deterioration of the results. The entire material investigated will also be analyzed in the same way, with regard to the combined total results.

In conformity with several other authors the material has been divided into 4 groups. Certain variations in the criteria used for the division of the material in relation to those of other authors could not be avoided. The difficulties in obtaining entirely comparable principles of classification are illustrated, for example, by the fact that Streli (1955) includes, in his total group of "Gut" knees, with a range of motion "from fully extended up to 70° flexed position", while Springorum (1966) considers that knees, with such a restriction of motion "up to 70°", can obviously not be regarded as "Gut".

An account of the criteria used for allocation of the patients to the different groups is given below:

Group Excellent: comprises 1. patients with no subjective complaints, objective symptoms and roentgenologic findings. 2. cases with roentgenologic signs of osteoarthritis of grade I, if no subjective complaints or objective symptoms were simultaneously present, and 3. cases with subjective complaints of the type *Good* (1+), if there were no roentgenologic findings.

To *group Good:* were allocated patients with 1. grade II roentgenologic findings at most, if at the same time the subjective complaints were not more than of the type *Good* (1+), and there were no objective symp-

toms. 2. Subjective complaints of type *Fair* (3+) or less, but with simultaneous grade I roentgenologic findings at most and no objective findings.

Group Fair: 1. Most of the patients in this group had grade II roentgenologic findings and subjective complaints varying between *Good and Fair*, with objective findings. 2. Here were also included cases with grade III roentgenologic osteoarthritis, but then in association with either mild or no subjective complaints of group *Good* or *Excellent* and with objective findings. 3. Patients with grade 0 or I roentgenologic findings, but with simultaneous subjective complaints of type *Bad*, and with objective findings, were also placed in this group.

Group Poor: All the patients in this group had grade III roentgenologic findings, subjective complaints varying between *Fair* and *Bad*, as well as objective findings.

Table 43 shows the distribution of the totally meniscectomized knees in accordance with the grouping described above.

TABLE 43 *Combined total results at follow-up in totally meniscectomized patients distributed in 4 groups M = males, F = females % = M + F*

Operated meniscus	Total Number		Excellent Number		Excellent %	Good Number		Good %	Fair Number		Fair %	Poor Number		Poor %
	M	F	M	F		M	F		M	F		M	F	
Medial	327	44	259	22	75.7	47	14	16.5	16	6	5.9	5	2	1.9
Lateral	57	12	41	8	71.0	14	3	24.7	2	1	4.3	0	0	0
Total	384	56	300	30	75.0	61	17	17.7	18	7	5.7	5	2	1.6

When comparing medially and laterally meniscectomized knees no significant differences were observed in respect of the combined late results.

A significantly higher frequency of unsatisfactory combined total results of group *Fair* and *Poor* was observed in the women as compared with the men (X^2 = 16.53*** d. f. = 2).

Comments

If a comparison is made between the results of this material and those reported by other authors, it will be found that more satisfactory combined late results were obtained in the present investigation than in several earlier series (Dengler 1938, Uebermuth 1941, Leuschner & Weickerd 1964, Herschmann 1965). However, better results have also

been reported by earlier authors (Streli 1955, Scheibe 1963, Strelec & Wozleka 1964, Springorum 1966). Comparison of reported observations from series where the material is allocated to 3 and 4 groups respectively gives no reliable results. If, however, the group *Poor* in the former classification is considered to correspond to groups *Fair* and *Poor* in the classification with 4 groups, the frequency of unsatisfactory combined total results will be approximately the same according to both systems of classification.

In the present material there was a significantly higher frequency of unsatisfactory total results in women compared with men, which verifies the results reported by some earlier authors (Aleman & Friberg 1934, Brechling 1942, Lagergren 1953, Barfod & Bierring 1956, Tapper & Hoover 1969).

With regard to the combined total results no significant differences existed between medially meniscectomized and laterally operated knees, a fact which does not agree with some earlier reports (Meier 1934, Aleman & Friberg 1934, Uebermuth 1941).

In what follows analyses of the combined total results will be made with regard to the same factors, as for the roentgenologic findings, the subjective complaint, and the objective symptoms.

a. AGE AT TIME OF OPERATION

It has been stated earlier that the more advanced the age of the patient at operation the higher will be the frequency of unsatisfactory results, and the conclusion has been drawn that in patients over 40—45, meniscectomy should be performed only if absolutely necessary (Raess 1930, Meier 1933, Dengler 1938, Scheibe 1963, Herschmann 1965). It has also been maintained, however, that the age of the patient at operation does not affect the subsequent total result (Andersson 1934, Barfod & Bierring 1956, Saugmann-Jensen 1963, Litchman et al. 1966). A lower mean age at operation for patients with unsatisfactory results in the operated knee has even been reported by Nitter (1946).

Own investigations

When correlating the combined total results with age at operation, for the entire material of total meniscectomies a higher frequency of unsatisfactory results of groups *Fair* and *Poor* was found for patients operated

TABLE 44 *Combined total results correlated with age at operation. M = males, F = females. % = M + F.*

Operated meniscus	Age at operation	Total Number M	Total Number F	Excellent Number M	Excellent Number F	Excellent %	Good Number M	Good Number F	Good %	Fair Number M	Fair Number F	Fair %	Poor Number M	Poor Number F	Poor %
Medial	Under 41 years	241	23	191	14	77.7	39	7	17.4	10	2	4.5	1	0	0.4
Lateral	Under 41 years	49	7	35	4	69.6	12	3	26.8	2	0	3.6	0	0	0
Total Under 41 years		290	30	226	18	76.2	51	10	19.1	12	2	4.4	1	0	0.3
Medial	Over 41 years	86	21	68	8	71.0	8	7	14.0	6	4	9.4	4	2	5.6
Lateral	Over 41 years	8	5	6	4	76.9	2	0	15.4	0	1	7.7	0	0	0
Total Over 41 years		94	26	74	12	71.7	10	7	14.2	6	5	9.1	4	2	5.0

when over 41 years compared with those operated before 41 (table 44). The difference is significant ($X^2 = 12.21^{**}$ d. f. = 2). A similar, significant difference was also obtained for medially meniscectomized ($X^2 = 10.78^{**}$ d. f. = 2), but not for laterally meniscectomized knees alone. A comparison for men and women separately showed an almost significantly higher frequency of unsatisfactory results for men operated after 41 years than for those operated before 41 ($X^2 = 6.65^{*}$ d. f. = 2). A similar difference for women was not significant.

Comments

In the present material a higher frequency of unsatisfactory combined results was found for patients operated when over 41 years compared with those operated under 41. This appears to verify observations reported by earlier investigators (Raess 1930, Meier 1933, Dengler 1938, Scheibe 1963, Herschmann 1965)

b LATENCY PERIOD

Higher frequency of unsatisfactory results of groups *Fair* and *Poor* has been reported following meniscectomy with long latency period, i. e. if a long time elapsed between trauma, or the onset of the complaint, and the operation (Meier 1933, Dengler 1938, Nitter 1946, Streli 1955, Barfod &

been reported by earlier authors (Streli 1955, Scheibe 1963, Strelec & Wozleka 1964, Springorum 1966). Comparison of reported observations from series where the material is allocated to 3 and 4 groups respectively gives no reliable results. If, however, the group *Poor* in the former classification is considered to correspond to groups *Fair* and *Poor* in the classification with 4 groups, the frequency of unsatisfactory combined total results will be approximately the same according to both systems of classification.

In the present material there was a significantly higher frequency of unsatisfactory total results in women compared with men, which verifies the results reported by some earlier authors (Aleman & Friberg 1934, Brechling 1942, Lagergren 1953, Barfod & Bierring 1956, Tapper & Hoover 1969).

With regard to the combined total results no significant differences existed between medially meniscectomized and laterally operated knees, a fact which does not agree with some earlier reports (Meier 1934, Aleman & Friberg 1934, Uebermuth 1941).

In what follows analyses of the combined total results will be made with regard to the same factors, as for the roentgenologic findings, the subjective complaint, and the objective symptoms.

a. AGE AT TIME OF OPERATION

It has been stated earlier that the more advanced the age of the patient at operation the higher will be the frequency of unsatisfactory results, and the conclusion has been drawn that in patients over 40—45, meniscectomy should be performed only if absolutely necessary (Raess 1930, Meier 1933, Dengler 1938, Scheibe 1963, Herschmann 1965). It has also been maintained, however, that the age of the patient at operation does not affect the subsequent total result (Andersson 1934, Barfod & Bierring 1956, Saugmann-Jensen 1963, Litchman et al. 1966). A lower mean age at operation for patients with unsatisfactory results in the operated knee has even been reported by Nitter (1946).

Own investigations

When correlating the combined total results with age at operation, for the entire material of total meniscectomies a higher frequency of unsatisfactory results of groups *Fair* and *Poor* was found for patients operated

Efskind 1939, Tapper & Hoover 1969). If the combined results are correlated with the latency periods, over and under 6 months respectively and at the same time with the age at operation, the length of the latency period will not be found to influence significantly the results for patients operated either before or after 41 years of age.

c. TYPE OF TRAUMA

Andersson (1934) and Streli (1955) consider that trauma as etiologic factor for the injury of the semilunar cartilage may be the cause of less satisfactory total results. Andersson (1934) found a fourfold unsatisfactory combined result for meniscectomies following a traumatic injury of the semilunar cartilage compared with nontraumatic cases. Tapper & Hoover (1969) consider that the less satisfactory results observed in *young patients, operated before the age of 20 were due to severe trauma* being responsible for the injury of the semilunar cartilage. A contrary opinion was held by Springorum (1966), who considers that less satisfactory results follow meniscectomies performed for nontraumatic ruptures. In such cases the rupture of the semilunar cartilage would be due to a higher degree of degeneration in both the semilunar cartilage and the knee as a whole, and hence the unsatisfactory results.

Own investigations

When correlating the combined groups of results after meniscectomy in traumatic and nontraumatic cases (table 46), no significant difference is found in the frequency of unsatisfactory results of groups *Fair* and *Poor*.

TABLE 46 *Combined total results correlated with the factor trauma* M = *males*, F = *females* % = M + F

Operated meniscus	Factor trauma	Total Number M	Total Number F	Excellent Number M	Excellent Number F	Excellent %	Good Number M	Good Number F	Good %	Fair Number M	Fair Number F	Fair %	Poor Number M	Poor Number F	Poor %
Medial	traumatic	279	36	225	19	77.5	36	12	15.2	14	5	6.0	4	0	1.3
Lateral	,,	36	5	24	3	65.8	11	1	29.3	1	1	4.9	0	0	0
Total	traumatic	315	41	249	22	76.1	47	13	16.9	15	6	5.9	4	0	1.1
Medial	nontraumatic	48	8	34	3	66.0	11	2	23.2	2	1	5.4	1	2	5.4
Lateral	,,	21	7	17	5	78.6	3	2	17.8	1	0	3.6	0	0	0
Total	nontraumatic	69	15	51	8	70.2	14	4	21.4	3	1	4.8	1	2	3.6

Bierring 1956, Scheibe 1963, Leuschner & Weickert 1964, Herschmann 1965). On this account these authors recommend that operation for ruptured semilunar cartilage should be performed as early as possible, but only after the acute symptoms have subsided. There are also some authors who were unable to find any clear-cut connection between the length of the latency period and a higher frequency of unsatisfactory results after a meniscectomy (Raess 1930, Spira 1933, Andersson 1934, Efskind 1939, Tapper & Hoover 1969). There is no unanimity about the demarcation line between a short and a long latency period, but many authors take 6 months as the borderline.

Own investigations

Table 45 shows the groups of combined results correlated with latency periods under and over 6 months. The small differences in the distribution of unsatisfactory results between short and long latency periods are not significant.

TABLE 45. *Combined total results correlated with the latency period. M = males, F = females. % = M + F.*

Operated meniscus	Latency period	Total Number		Excellent Number		%	Good Number		%	Fair Number		%	Poor Number		%
		M	F	M	F		M	F		M	F		M	F	
Medial	Under 6 months	177	28	142	13	75.6	24	9	16.1	10	5	7.3	1	1	1.0
Lateral	Under 6 months	27	2	18	1	65.5	8	0	27.6	1	1	6.9	0	0	0
Total	Under 6 months	204	30	160	14	74.4	32	9	17.5	11	6	7.3	1	1	0.8
Medial	Over 6 months	150	16	117	9	75.9	23	5	16.9	6	1	4.2	4	1	3.0
Lateral	Over 6 months	30	10	23	7	75.0	6	3	22.5	1	0	2.5	0	0	0
Total	Over 6 months	180	26	140	16	75.8	29	8	17.9	7	1	3.9	4	1	2.4

Comments

In the present material it was not possible to demonstrate a deterioration in the combined results due to a longer latency period. This agrees with the conception that the length of the latency period does not affect the postoperative combined results (Raess 1930, Spira 1933, Andersson 1934,

Comments

The results of this material show that the length of the observation period does not play any part in the development of the combined results, which is in agreement with the earlier reports mentioned above.

e. OTHER FACTORS POSSIBLY CAUSING DETERIORATION OF RESULTS

Preoperative clinical findings

MacAusland (1931) considers that preoperative clinical findings, such as lockings, effusion or combinations of these can often cause unsatisfactory combined results. Barfod & Bierring (1956), on the other hand, concluded that the frequency of lockings and effusion have no detrimental influence on the combined results.

Own investigations

As is evident from table 48, preoperative clinical findings were about equally distributed among the groups of combined total results. Existing small differences, with regard of unsatisfactory results, between knees with or without preoperative clinical findings were not significant.

TABLE 48 *Combined total results correlated with preoperative findings M = males, F = females % = M + F*

Preoperative findings	Total Number		Excellent		Good		Fair		Poor	
	M	F	M	F	M	F	M	F	M	F
Only lockings	99	10	80	6	14	3	3	0	2	1
effusion	86	24	65	14	14	7	7	3	0	0
,, haemarthrosis	4	0	4	0	0	0	0	0	0	0
Lockings + effusion	113	8	86	3	20	2	4	3	3	0
,, + haemarthrosis	8	0	7	0	1	0	0	0	0	0
Total with preop. find.	310	42	242	23	49	12	14	6	5	1
%	100.0		75.3		17.3		5.7		1.7	
Without preop. findings	74	14	58	7	12	5	4	1	0	1
%	100.0		73.9		19.3		5.7		1.1	

Comments

Contrary to Andersson (1934), Streli (1955) and Tapper & Hoover (1969), in the present material there is no significant difference in the combined results after meniscectomy between traumatic and non-traumatic cases. Nor do the present results verify the view, that less satisfactory results would be achieved after meniscectomy in nontraumatic cases (Springorum 1966).

d. OBSERVATION PERIOD

Many authors consider that a sufficiently long observation period is required in order to be able to assess the late results following a meniscectomy. The length of a sufficiently long observation period is estimated, however, differently by different authors and, varies between 10 and 20 years; in general about 14—15 years.

It has been stated in this context that the length of the observation period does not play any role in the quality of the late results (Brechling 1942, Barfod & Bierring 1956, Herschmann 1965). Better results have been reported, however, after a long observation period (Meier 1933, Spira 1933, Springorum 1966), but there are also reports to the contrary (Nitter 1946).

Own investigations

As is evident from table 47 only small differences existed between the various groups of observation periods in respect of unsatisfactory combined results of groups *Fair* and *Poor*. These differences were not significant.

TABLE 47. *Combined total results correlated with the observation period M = males, F = females % = M + F*

Period of observation	Total Number		Excellent Number		Excellent %	Good Number		Good %	Fair Number		Fair %	Poor Number		Poor %
	M	F	M	F		M	F		M	F		M	F	
4—13 years	219	44	179	26	78.0	27	13	15.2	9	4	4.9	4	1	1.9
14—23 „	106	8	79	4	72.8	21	2	20.2	6	1	6.1	0	1	0.9
24—33 „	53	4	36	0	63.2	13	2	26.3	3	2	8.8	1	0	1.7
34—43 „	6	0	6	0	100.0	0	0	0	0	0	0	0	0	0
Total	384	56	300	30		61	17		18	7		5	2	

Postoperative complications

Efskind (1939) stated that in his series less satisfactory results were observed consistently in patients with prolonged effusion in the joint after a meniscectomy.

Own investigations

The frequency of different postoperative complications with regard to the combined results is demonstrated in table 50. No patient belonging to group Poor had had such complications. No statistically significant differences in the frequency of unsatisfactory results of group *Fair* and *Poor* were found between patients with or without different postoperative complications.

TABLE 50 *Combined total reults correlated with postoperative complications*
M = males, F = females

Postoperative complications	Total Number		Excellent		Good		Fair		Poor	
	M	F	M	F	M	F	M	F	M	F
Persisting effusion	14	1	7	1	6	0	1	0	0	0
Haemarthrosis	19	1	13	1	5	0	1	0	0	0
Signs of infection	19	2	17	1	2	0	0	1	0	0

Comments

The results obtained from the present material show that postoperative complications do not cause deterioration of the combined late results. This observation is contrary to the findings of Efskind (1939).

Postoperative treatment

Fixation with some type of splint or plaster is applied as a postoperative routine by many authors. Several others prescribe *muscular training* as part of their routine. No information is given, however, about the effect of these therapeutic managements on the combined results after meniscectomy. There is lack of information also regarding the influence of various routine measures on the late results: when postoperatively the patient is allowed to begin *weight bearing* on his leg, and the length of *postoperative hospitalization*

Comments

In contrast to the data reported by MacAusland (1931), the present observations show that existence of preoperative clinical findings did not influence significantly the combined late results. This is in agreement with the results reported by Barfod & Bierring (1956).

Secondary findings at operation

Existence of varying intra-articular changes, among others, degenerative arthritis and lesions of the ligaments, diagnosed at the time of meniscectomy, have been reported to deteriorate the prognosis concerning the combined late results (Streli 1955, Springorum 1966, Mohing 1966).

Own investigations

Table 49 shows the frequency of different secondary findings at operation. On account of the few cases with secondary findings at operation, other than osteoarthritis, it was not possible to analyze these statistically. The frequency of unsatisfactory total results of groups *Fair* and *Poor* was, however, found to be higher in patients with than without osteoarthritis diagnosed at operation. The observed difference was highly significant ($X^2 = 26.44^{***}$ d. f. = 3).

TABLE 49. *Combined total results correlated with the various operative findings M = males, F = females*

Operative findings	Total Number		Excellent		Good		Fair		Poor	
	M	F	M	F	M	F	M	F	M	F
Injuries of coll lig	3	1	1	1	2	0	0	0	0	0
" " cruc. "	5	0	5	0	0	0	0	0	0	0
Chondr patellae	9	2	4	1	2	1	2	0	1	0
Osteochondr. dissec	8	1	5	0	1	1	1	0	1	0
Osteoarthritis	32	10	19	5	5	3	5	1	3	1

Comments

The existence of osteoarthritis at operation has been shown to deteriorate significantly the combined late results after meniscectomy. The role possibly played by other secondary findings at operation could not be analyzed statistically on account of the few cases with such findings according to the available information in the hospital records.

Postoperative complications

Efskind (1939) stated that in his series less satisfactory results were observed consistently in patients with prolonged effusion in the joint after a meniscectomy.

Own investigations

The frequency of different postoperative complications with regard to the combined results is demonstrated in table 50. No patient belonging to group Poor had had such complications. No statistically significant differences in the frequency of unsatisfactory results of group *Fair* and *Poor* were found between patients with or without different postoperative complications.

TABLE 50 *Combined total reults correlated with postoperative complications*
M = males, F = females

Postoperative complications	Total Number		Excellent		Good		Fair		Poor	
	M	F	M	F	M	F	M	F	M	F
Persisting effusion	14	1	7	1	6	0	1	0	0	0
Haemarthrosis	19	1	13	1	5	0	1	0	0	0
Signs of infection	19	2	17	1	2	0	0	1	0	0

Comments

The results obtained from the present material show that postoperative complications do not cause deterioration of the combined late results. This observation is contrary to the findings of Efskind (1939).

Postoperative treatment

Fixation with some type of splint or plaster is applied as a postoperative routine by many authors. Several others prescribe *muscular training* as part of their routine. No information is given, however, about the effect of these therapeutic managements on the combined results after meniscectomy. There is lack of information also regarding the influence of various routine measures on the late results: when postoperatively the patient is allowed to begin *weight bearing* on his leg, and the length of *postoperative hospitalization*

Own investigations

During the long period covered by this material a number of routines must have been prevalent with regard to the above-mentioned postoperative forms of treatment. Thus, information on postoperative muscular training has been obtained for 199 patients, and application of postoperative fixation for 171 patients. This enables statistical analysis of the observed differences, and, hence reliable information can be obtained regarding the influence of these therapeutic measures on the combined results.

TABLE 51. *Combined total results correlated with different forms of postoperative treatment. M = males, F = females. % = M + F.*

Postoperative treatment	*Total Number*		*Excellent*		*Good*		*Fair*		*Poor*	
	M	F	M	F	M	F	M	F	M	F
Muscular training	170	29	143	17	19	9	6	2	2	1
%	100		80.4		14.1		4.0		1.5	
Without training	*214*	*27*	*157*	*13*	*42*	*8*	*12*	*5*	*3*	*1*
%	100		70.5		20.7		7.1		1.7	
Fixation by splint or plaster	150	21	120	11	22	7	4	2	4	1
%	100		76.6		17.0		3.5		2.9	
Without fixation	234	35	180	19	39	10	14	5	1	1
%	*100*		*74.0*		*18.2*		*7.1*		*0.7*	

Table 51 shows the allocation of the material to the different groups of combined total results, for the cases where muscular training was applied, and for patients treated with postoperative fixation separately. There were no significant differences in the frequency of unsatisfactory combined results between patients who were prescribed postoperative muscular training and those who were not, or between patients treated with or without postoperative fixation.

When correlating the combined late results with the time when weight bearing was first allowed postoperatively (table 52), it was found that the frequency of unsatisfactory results was higher for patients who began weight bearing later compared with those who began earlier, i. e. within 2 weeks after the operation. The differences were statistically significant ($X^2 = 13.66^{**}$ d. f. = 4).

The length of hospitalization did not influence significantly the frequ-

TABLE 52. *Combined total results correlated with the time when weight bearing was first allowed after the operation M = males, F = females % = M + F.*

Postoper. weight bearing allowed	Total Number		Excellent Number		%	Good Number		%	Fair Number		%	Poor Number		%
	M	F	M	F		M	F		M	F		M	F	
Within 1 week	40	2	34	2	85.6	3	0	7.2	3	0	7.2	0	0	0
„ 8—14 days	258	31	203	19	76.8	43	10	18.3	9	2	3.8	3	0	1.1
After 2 weeks	86	23	63	9	66.1	15	7	20.2	6	5	10.1	2	2	3.6
Total	384	56	300	30		61	17		18	7		5	2	

TABLE 53 *Combined total results distributed according to length of postoperative hospitalization M = males, F = females % = M + F.*

Postoperative hospitalization	Total Number		Excellent Number		%	Good Number		%	Fair Number		%	Poor Number		%
	M	F	M	F		M	F		M	F		M	F	
1 week	5	0	5	0	100.0	0	0	0	0	0	0	0	0	0
8—14 days	180	19	136	13	74.9	34	6	20.1	8	0	4.0	2	0	1.0
Over 2 weeks	199	37	159	17	74.6	27	11	16.1	10	7	7.2	3	2	2.1
Total	384	56	300	30		61	17		18	7		5	2	

ency of unsatisfactory late results in patients discharged within the first two weeks after meniscectomy or later (table 53).

Comments

The fact that postoperative muscular training does not influence the frequency of unsatisfactory late results may not be surprising. Postoperative fixation was, however, expected to cause bad results, as was the case with roentgenologic findings[8]) and objective symptoms. It is evident, however, that the fact that subjective complaints, were not influenced by postoperative fixation, probably affected the combined results to a greater extent than did the roentgenologic findings and the objective symptoms together The observation that a delayed start with weight bearing caused significantly less satisfactory results is difficult to explain. It is possible, however, that patients with preoperative signs of roentgenologic osteoarthritis, osteoarthritis diagnosed at operation, or advanced age at operation, were not allowed early weight bearing and then the bad late results must be assigned to these factors rather than to the time of weight bearing per se

[8]) see footnote page 41

Age at the follow-up investigation

The mean age at the follow-up investigation was for patients with total meniscectomy 47.5 ± 0.6 years. When age at the follow-up investigation is correlated with the different groups of combined late results (table 54) there is a distinctly higher frequency of unsatisfactory results of group *Fair* and *Poor* for patients over 61 compared with younger persons at the time of the follow-up. The differences were highly significant (X^2 = 19.60*** d. f. = 4). A further correlation with different observation periods did not show any statistically significant effect on the results for the different age groups at the time of the follow-up.

TABLE 54. *Combined total results distributed by patients' age at the follow-up examination. M = males, F = females. % = M + F.*

Age at follow-up	Total Number		Excellent Number		%	Good Number		%	Fair Number		%	Poor Number		%
	M	F	M	F		M	F		M	F		M	F	
Under 41 years	118	19	98	12	80.3	16	6	16.1	4	1	3.6	0	0	0
41—60 ,,	212	25	162	13	73.8	39	9	20.3	9	2	4.6	2	1	1.3
Over 61 ,,	54	12	40	5	68.2	6	2	12.1	5	4	13.6	3	1	6.1
Total	384	56	300	30		61	17		18	7		5	2	

Comments

The observation of a higher frequency of unsatisfactory combined late results in patients over 61 at the time of the follow-up compared with younger patients can hardly be explained by any cause other than generalized changes of the knee with advancing age; meniscectomy might possibly promote the rapid development of such changes.

Sport and occupation after operation

Raess (1930) reported that the degree of occupational strain for the operated knee after the operation does not influence the late results and Meier (1933) stated that all the patients in his own material were able to return after the operation to their previous, often heavy, work.

Own investigations

Practising of sport after the operation did not cause deterioration in the combined late results (table 55). That so few of those who practised

TABLE 55 *Combined total results distributed according to the factor postoperative sport M = males, F = females*

Postoperative sport	Total		Excellent		Good		Fair		Poor	
	M	F	M	F	M	F	M	F	M	F
Medial	117	2	104	1	11	1	2	0	0	0
Lateral	22	0	18	0	4	0	0	0	0	0
Total	139	2	122	1	15	1	2	0	0	0

athletic activities after operation were placed in the groups *Fair* or *Poor*, can hardly be due to the fact, however, that sport after operation improved the results; it is more probable that patients with knee complaints after meniscectomy abstained from sport.

When the degree of occupational strain is correlated with the different groups of combined total results (table 56), it is found that the lowest frequency of unsatisfactory results occurred among those patients who, after operation, had the most knee-straining work. No statistically significant differences in the frequency of unsatisfactory late results were found for patients with heavier work compared with those having less knee-straining work after operation.

TABLE 56 *Combined total results distributed by type of occupational knee strain after operation M = males, F = females % = M + F*

Type of work after operation	Total Number		Excellent Number		Excellent %	Good Number		Good %	Fair Number		Fair %	Poor Number		Poor %
	M	F	M	F		M	F		M	F		M	F	
Mainly sitting work	57	10	45	7	77 6	7	3	14 9	5	0	7.5	0	0	0
Moderately knee-straining work	212	43	163	21	72 2	36	14	19 6	9	6	5 9	4	2	2 3
Knee-straining work	115	3	92	2	79 7	18	0	15 3	4	1	4 2	1	0	0 8
Total	384	56	300	30		61	17		18	7		5	2	

Comments

The results of the present investigation show that sport after meniscectomy does not aggravate the late results for the operated knee. This investigation also verifies earlier reports, namely, that the type of postoperative occupation does not influence the combined total results (Raess 1930, Meier 1933).

f. SUMMARY OF THE COMBINED TOTAL RESULTS

The results reported in this part can be summarized as follows:

a. In the present material of totally meniscectomized knees no significant differences, between medially and laterally operated knees, could be demonstrated with regard to the combined total results. The frequency of unsatisfactory total results was, however, higher for women compared with men, and this difference is highly significant (X^2 = ***).

b. Patients over 41 years at time of operation showed a higher frequency of unsatisfactory combined results of group *Fair* and *Poor* compared with patients under 41 at operation. Differences obtained in this respect are significant for the entire material of total meniscectomies (X^2 = **) and for medially operated knees alone (X^2 = **), and almost significant for men alone (X^2 = ·). For laterally operated knees and for women separately the differences were not significant.

c. The length of the latency period was not of significant importance for the occurrence of unsatisfactory combined late results after meniscectomy.

d. No significant differences, could be shown in the combined results after meniscectomy, between patients whose lesion of the semilunar cartilage was of traumatic origin and those where it was not.

e. No significant differences, in the frequency of unsatisfactory total results of group *Fair* and *Poor* could be shown to exist in this material, between patients with shorter and longer observation periods respectively.

f. The occurrence of preoperative clinical findings has not been found to cause deterioration of the combined late results to a significant extent.

g. Osteoarthritis established at operation has caused a highly significant deterioration of the combined late results after meniscectomy (X^2 = ***).

h. Postoperative complications, such as effusion, haemarthrosis or signs of infection have not been shown to be of significant importance for the combined late results.

i. Muscular training or fixation after the operation had no significant influence on the late results.

j. The length of hospitalization did not influence the frequency of unsatisfactory results in a significant way. However, significantly higher frequency of unsatisfactory combined total results occurred in cases where weight bearing was allowed first after the 2nd postoperative week than in those where it was introduced earlier (X^2 = **).

k. The frequency of unsatisfactory results was significantly higher for

patients over 61 at the follow-up investigation compared with those under 61 (X^2 = **).

l. Athletic activities after operation do not seem to have caused deterioration of the late results after meniscectomy. Nor has occupational knee-strain postoperatively influenced the combined late results in any significant way.

5. TOTAL MENISCECTOMIES EXCLUDING CASES WITH PREOPERATIVE ROENTGENOLOGIC OSTEOARTHRITIS OR OSTEOARTHRITIS DIAGNOSED AT OPERATION

In earlier investigations of meniscectomized patients no special attention has been paid to cases with preoperative roentgenologic signs of osteoarthritis. Materials including such cases are inhomogeneous and the latter might, therefore, influence the degree of significance of the obtained results. Preoperative roentgenograms available for comparison at the time of follow-up examination restrict to some extent such an undesired interference.

The material reported on hitherto has included all cases of total meniscectomy. As mentioned earlier, preoperative radiographies were not available during the follow-up investigation. In order to ascertain whether the obtained results were influenced in any degree by the presence in the material of such patients as had preoperative roentgenologic signs of osteoarthritis or osteoarthritis diagnosed at operation, these cases were excluded and then the remaining material was analyzed in respect of roentgenologic findings and combined late results. A short account of the most important results obtained from these analyses will be given herewith.

TABLE 57 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis by age at operation. Patients with preoperative roentgenologic osteoarthritis or osteoarthritis diagnosed at operation are excluded. M = males, F = females. % = M + F*

Age at operation	Total Number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
	M	F	M	F		M	F		M	F		M	F	
Under 41 years	270	26	159	14	58 5	87	9	32 4	22	3	8 5	2	0	0 6
Over 41 "	66	16	33	8	50 0	32	6	46.3	1	2	3 7	0	0	0
Total	336	42	192	22	56 6	119	15	35 5	23	5	7 4	2	0	0.5

When, after this exclusion, roentgenologic osteoarthritis at follow-up is correlated with age at time of operation, *there is no significant difference in the frequency of degenerative arthritis of grade II and III between patients operated before or after 41 years of age* (table 57). The same conditions were found to exist on correlating the combined late results with age at operation.

The length of the latency periods shows no significant influence on either the frequency of roentgenologic osteoarthritis or the frequency of unsatisfactory combined results.

The length of the observation period showed, even under these conditions, a highly significant increase in the frequency of roentgenologic osteoarthritis in the groups with longer observation period ($X^2 = 30.65$*** d. f. = 4). On the other hand, an almost significant higher *frequency* of unsatisfactory combined late results of groups *Fair* and *Poor* was obtained in the new analysis with increasing length of the observation period ($X^2 = 11.03$* d. f. = 4), which was not the case when the total number of meniscectomies was analyzed.

TABLE 58. *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis according to postoperative muscular training Patients with preoperative roentgenologic osteoarthritis or osteoarthritis diagnosed at operation are excluded.*

	Total	Group 0		Group I		Group II		Group III	
	Number	Number	%	Number	%	Number	%	Number	%
Muscular training	157	102	65.0	50	31 8	5	3 2	0	0
No muscular training	221	112	50.7	84	38 0	23	10.4	2	0 9
Total	378	214		134		28		2	

TABLE 58 a *Combined total results distributed according to postoperative muscular training Patients with preoperative roentgenologic osteoarthritis or osteoarthritis at operation are excluded*

	Total	Excellent		Good		Fair		Poor	
	Number	Number	%	Number	%	Number	%	Number	%
Muscular training	157	136	86 6	18	11 5	3	1 9	0	0
No muscular training	221	160	72 4	46	20 8	14	6 3	1	0 5
Total	378	296		64		17		1	0 5

Patients, who received postoperative muscular training, compared with those who did not, *showed a highly significant decrease in frequency of*

TABLE 59 *Distribution of totally meniscectomized knees in the different groups of roentgenologic osteoarthritis at follow-up according to postoperative fixation. Patients with preoperative roentgenologic osteoarthritis or osteoarthritis diagnosed at operation are excluded.*

	Total	Group 0		Group I		Group II		Group III	
	Number	Number	%	Number	%	Number	%	Number	%
Fixation postoperatively	147	77	52.4	65	44.2	4	2.7	1	0.7
No fixation "	231	137	59.3	69	29.9	24	10.4	1	0.4
Total	378	214		134		28		2	

roentgenologic osteoarthritis ($X^2 = 11.93^{***}$ d. f. = 2) *as well as unsatisfactory combined results* ($X^2 = 163.90^{***}$ d. f. = 2) (table 58 and 58 a).

From table 59 it is evident that *patients treated with fixation with splints after operation showed a lower frequency of roentgenologic osteoarthritis* of grade II and III when compared with patients treated without fixation. The difference is highly significant ($X^2 = 12.21^{***}$ d. f. = 2). On the other hand, even now there was no difference in respect of unsatisfactory combined results between patients with or without postoperative fixation.

The time when weight bearing was first allowed and the length of hospitalization did not show any significant differences with regard to roentgenologic osteoarthritis or unsatisfactory combined results. Apparently the previously observed significant differences in this respect were due to the fact that patients, with preoperative roentgenologic signs of degenerative arthritis or osteoarthritis at time of operation, were allowed to start weight bearing later and were also discharged from hospital later.

CHAPTER V

Results of follow-up investigation after partial meniscectomy

Reports regarding results of follow-up investigations of partially meniscectomized patients are scarce (table 41). Streli (1955), and Böhler (1955) have reported the results for a material consisting solely of partial meniscectomies. Scheibe (1963) and Leuschner & Weickert (1964) present results for totally and for partially meniscectomized knees separately. Tapper & Hoover (1969) state that the results after partial meniscectomy are not more satisfactory than after total meniscectomy, except when partial meniscectomy is performed in cases of so-called "bucket-handle" ruptures of the semilunar cartilage, where the results are better. Streli (1955) reported separately the results for roentgenologic findings and for combined total results, but not for subjective complaints or objective symptoms.

The material under review comprised only 21 partially resected cases, 17 of which were medially and 4 laterally meniscectomized. Only 2 women were partially meniscectomized, both medially. This material is too small to afford any possibility of an analysis similar to that of the material of total meniscectomies. A short account of this material will, however, be given.

1. ROENTGENOLOGIC RESULTS

In accordance with the principles of classification applied for the totally meniscectomized knees, the partial meniscectomies can be grouped as shown in table 60 (p. 86). The frequency of roentgenologic signs of degenerative arthritis was 9.5 per cent. *Compared with the results obtained* by Streli (1955) (table 41) who reported cases with osteoarthritis in 14.6 per cent, the results of the present material seem to be somewhat more

satisfactory. With regard to the frequency of roentgenologic findings of osteoarthritis, there were no significant differences between totally and partially meniscectomized knees.

Only one patient was operated when over 41. Twenty patients were younger than 41 at time of operation. The two patients in group II were operated with a latency period less than 6 months, and in both the rupture of the semilunar cartilage was of traumatic origin. — Regarding the observation period these two patients belonged to group 14—23 years. Moreover, it may be mentioned that none of the partially meniscectomized patients had postoperative complications.

2. SUBJECTIVE COMPLAINTS

When classifying the material into different groups with regard to the subjective complaints, the same criteria were used as for total meniscectomies Fifteen men and 1 woman among the partially meniscectomized patients were allocated to the group *Excellent*, 3 men and 1 woman to the group *Good*, and only 1 man to the group *Fair*. None of these patients had subjective complaints of the type *Bad* When the frequency of subjective complaints of groups *Fair* and *Bad* was compared between partially and totally meniscectomized patients no significant differences were found.

3. OBJECTIVE SYMPTOMS

With regard to objective symptoms the partially meniscectomized patients were assessed in the same way as the totally meniscectomized. Seventeen men and 1 woman belonged to the *normal* group, and 2 men and 1 woman to the group *with symptoms*. There was no significant difference between totally meniscectomized and partially meniscectomized knees in the frequency of cases with symptoms.

4 COMBINED RESULTS FOR PARTIAL MENISCECTOMIES

The principles used for the assessment of the combined results for the totally meniscectomized knees were also used for the partially operated. Fifteen men and 2 women belonged to the group *Excellent*, 3 men to the group *Good*, and 1 man to the group *Fair*. Observed differences in frequency of unsatisfactory combined results between totally and partially meniscectomized patients were not significant.

TABLE 60. *Partially meniscectomized patients distributed by different groups of roentgenologic osteoarthritis at follow-up. M = males, F = females. % = M + F.*

Operated meniscus	Total Number		Group 0 Number		%	Group I Number		%	Group II Number		%	Group III Number		%
	M	F	M	F		M	F		M	F		M	F	
Medial	15	2	9	2	64.7	5	0	29.4	1	0	5.9	0	0	0
Lateral	4	0	3	0	75.0	0	0	0	1	0	25.0	0	0	0
Total	19	2	12	2	66.7	5	0	23.8	2	0	9.5	0	0	0

TABLE 61. *"Double-operated" knees distributed according to the combined total results.*

"Double-operated" knees	Excellent	Good	Fair	Poor
Both knees medial	18	2	0	0
One medial + other lateral	3	3	0	0
Same knee medial and lateral	4	1	1	0
Number of operated knees	25	6	1	0

CHAPTER VI

"Double-operated"

There are few reports regarding cases where more than one semilunar cartilage was removed and in none are the results of such cases analyzed separately. Streli (1955) reported one "double-operated" patient in his material. Springorum (1966) had in his material 51 patients in whom more than one semilunar cartilage was operated. Leuschner & Weickert (1964) stated that they had only 2 "double-operated" patients.

Own results

Here an account is given of 19 patients in whom 2 different semilunar cartilages were operated, either at the same operation or on two different occasions, in the same or in both knees. These patients were separated from the main material in order to make it as homogeneous as possible. Table 61 shows the grouping of the "double-operated" patients, with regard to the combined results. In the knee in the *Fair* group both semilunar cartilages were operated on the same occasion 20 years after the onset of the symptoms. The observation period was 8 years. The patient's disorder was almost entirely localized in the lateral side, where roentgenologic changes of type II were found. The patient had only moderate subjective complaints and objective symptoms.

On account of the character of the material, the results of these observations cannot be treated in the same way as in the main material. However, the following observation may be pointed out. No significant differences in the frequency of unsatisfactory combined results were found on comparing "double-operated", partially meniscectomized, and totally meniscectomized knees.

CHAPTER VII

Re-operations

In the dispute between the advocates of total meniscectomy and the adherents to partial meniscectomy, re-operations have also been used as an argument. It has, thus, been stated that after partial meniscectomy a new rupture of the remaining semilunar cartilage occurs only in about 0.5—1.0 per cent of the cases, while the risk for a new rupture after total meniscectomy is 3.0—5.0 per cent (Böhler 1955). Streli (1955) stated that in his material of 82 partially meniscectomized patients, and with an observation period of between 18 and 25 years, there was no case of relapse.

On the other hand, authors who advocate total extirpation of the semilunar cartilage maintain that a new rupture is rather usual after partial meniscectomy in the residual part of the cartilage, as sometimes also occurs after total meniscectomy (Andreesen 1937, Stumpfegger 1940, Schaefer 1953, Mandl 1954, Schilling 1963, Springorum 1966). Scheibe (1963) reported that among 127 total meniscectomies recurrence occurred in only 2 cases (1.5 per cent).

Own results

In this material, consisting of 480 meniscectomized and followed-up patients, there were 5 cases or 1.04 per cent where a new operation on a previously operated semilunar cartilage was necessitated. Of these five patients one had previously undergone partial resection of the semilunar cartilage, and in four total meniscectomy had been performed at the first operation. The percentage of a rupture of the "regenerate" after total meniscectomy, i. e. 0.9 per cent, diverged from that reported by Bohler.

CHAPTER VIII

General discussion

Operation on account of injuries of the semilunar cartilage in the knee tends to become more usual. The possibility of verifying the clinical diagnosis by means of arthrography is probably one of the reasons which contributed towards this development. The existence of several reports of a varying, but nonetheless unambiguous, frequency of roentgenologic osteoarthritis and unsatisfactory combined results after meniscectomy, gives rise to the question whether meniscectomy is an entirely safe and invariably necessary operation.

Access to a fairly large material of meniscectomies and the results of a follow-up investigation performed personally by the author made it possible to provide statistically verified data and thus, increase our knowledge of the fate of the meniscectomized knee in several respects. The following main questions put in the introduction can now be answered.

1. TO WHAT EXTENT DOES ROENTGENOLOGIC OSTEO-ARTHRITIS OCCUR AFTER MENISCECTOMY?

A significantly higher frequency of different signs of degenerative arthritis in the operated than in the nonoperated control knee is clearly demonstrated in this investigation. Thus, when the different signs of osteoarthritis are allocated to four groups it is found that patients with pronounced or severe roentgenologic signs of osteoarthritis in the operated knee represent 10.8 per cent of all totally meniscectomized knees. In the nonoperated knees the frequency of osteoarthritis was only 0.9 per cent. The frequency of roentgenologic signs of osteoarthritis in the meniscectomized knee has been reported to vary between 6.8 per cent (Rothascher

1960) and 40 per cent (Efskind 1939). In general, a substantially higher frequency of osteoarthritis in the operated knee has been reported than that observed in this material. Thus, besides Efskind, who has already been mentioned, Nitter (1946) reported a frequency of 34.3 per cent, and Franke (1966) a frequency of osteoarthritis in the operated knee of 38.8 per cent.

Conclusions

Different roentgenologic signs of osteoarthritis occur in a significantly higher frequency after meniscectomy in the operated knee compared with the nonoperated control knee in the same patients. The frequency of pronounced or severe osteoarthritis in the operated knee is 10.8 per cent[9]) *of all the totally meniscectomized knees. This relatively low frequency of* knees with a considerable degree of osteoarthritis can hardly lead to the conclusion that one should abstain from removing a ruptured semilunar cartilage in the knee, despite the fact that osteoarthritis in the nonoperated knee was observed in only 0.9 per cent of the cases. No certain information exists on the extent of osteoarthritis which can occur in knees with an injured semilunar cartilage that is not operated.

2. TO WHAT EXTENT DO SUBJECTIVE COMPLAINTS, OBJECTIVE FINDINGS AND UNSATISFACTORY COMBINED RESULTS OCCUR AFTER MENISCECTOMY?

Subjective complaints in the meniscectomized knee occurred somewhat less frequently than roentgenologic findings in this material. There were 8.6 per cent of the patients who had distinct subjective complaints. The degree of subjective complaints was not always in agreement with the degree of roentgenologic findings. Thus, patients with substantial subjective complaints could be entirely without signs of roentgenologic osteoarthritis and vice versa.

The frequency of subjective complaints reported by different authors varies considerably. These variations are probably due to differences in the way the data were collected. If the frequencies obtained in the pre-

9) see footnote page 30

sent material are compared with those reported by authors who, as in this material, obtained their information by means of personal interrogation (Birgfeld 1928, Aleman & Friberg 1934, Saugmann-Jensen 1963, Franke 1966), then, the frequencies of subjective complaints in the material under review are somewhat lower than those earlier reported.

The frequency of objective findings was still lower than that for subjective complaints and for roentgenologic findings. When the group *Excellent* for subjective complaints is compared with the group *Normal* for objective findings the frequencies are 62.3 per cent and 80.2 per cent respectively. Patients with objective findings could be entirely without signs of roentgenologic osteoarthritis or subjective complaints or vice versa.

There are very few other authors who have reported their results for objective findings separately. Usually these are evaluated together with the subjective complaints. Normal findings were reported by Efskind (1939) only in 40 per cent of his cases, whereas Saugmann-Jensen (1963) reported 70 per cent normal objective findings in his series.

If the roentgenologic findings, subjective complaints and objective symptoms were taken together, in order to estimate the combined total results, then 7.3 per cent of the operated knees gave unsatisfactory results of groups *Fair* and *Poor*.

Despite the fact that the classification used by several authors is in general similar to that used for the present material, reported results are largely divergent. Thus, Dengler (1938) reported unsatisfactory combined results in 33.8 per cent of the patients, and Tapper & Hoover (1969) in 32.0 per cent, on the other hand, Streli (1955) had only 1.2 per cent of cases with unsatisfactory results, and Springorum (1966) 1.3 per cent.

In the present material the frequency of unsatisfactory combined results was significantly higher for women than for men. Similar observations have also been reported by other authors, but only Tapper & Hoover found existing differences to be statistically significant.

Conclusions

The frequency of both subjective complaints and objective symptoms was lower than that of the roentgenologic findings, and this affects the combined results to some extent. Thus, there were 7.3 per cent of unsatisfactory combined results compared with 10.8 per cent of roentgenologic osteoarthritis in the meniscectomized knees. It is further evident that the combined results are influenced by the sex of the patients. Women show a significantly higher frequency of unsatisfactory combined results than men.

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3. DOES AGE AT TIME OF OPERATION AFFECT THE RESULTS?

In all total meniscectomies in the present material a significantly higher frequency of roentgenologic osteoarthritis was established in patients operated when over 41 years than in those under 41. Objective symptoms also showed a significantly higher frequency for patients operated when over 41, while, on the other hand, subjective complaints did not show any significant difference in relation to age at operation. The frequency of unsatisfactory combined results was significantly higher for patients operated when over 41 years than for those under 41.

A higher frequency of roentgenologic osteoarthritis in elderly patients at the time of the operation was reported by Scheibe (1963) and Herschmann (1965) among other investigators. A higher frequency of subjective complaints in operated patients of advanced age was reported by MacAusland (1931) and Saugmann-Jensen (1963). Higher frequency of unsatisfactory combined results for older patients at operation has been reported by several authors (Raess 1930, Meier 1933, Degler 1938, Scheibe 1963, Herschmann 1965). Many of these authors consider that injuries of the semilunar cartilage in patients over 40—45 should not be operated unless the intensity of the symptoms makes the intervention absolutely necessary.

As part of the investigation, meniscectomized knees with preoperative roentgenologic osteoarthritis or demonstrable osteoarthritis at operation were excluded from the total material, in order to ascertain the effect of the operation on a more homogeneous material. When the remaining meniscectomies are correlated with age at operation there is no significant difference, between patients operated when either over 41 or under 41, with regard to the frequency of roentgenologic signs of osteoarthritis or of unsatisfactory combined results. This is in agreement with the statement that there is no difference between older and younger operated patients with regard to the combined results (Nitter 1946, Lagergren 1953, Barfod & Bierring 1956, Monn 1964, Huckell 1965). Litchman et el. (1966) reported "Excellent" combined results in a series where all patients were at least 60 years old at time of operation.

Conclusions

The statement that a meniscectomy should not be performed on persons of advanced age must be regarded as too far-reaching. There is, however, reason to be more restrictive about operating on elderly patients if

roentgenologic osteoarthritis is present already preoperatively. If this is not the case, then there does not seem to be any reason why a diagnosed injury of the semilunar cartilage should not be operated in elderly patients, for the same indications as those for younger patients.

4. IS THE LENGTH OF THE LATENCY PERIOD OF ANY IMPORTANCE FOR THE RESULTS AFTER MENISCECTOMY?

The length of the latency period had no significant influence on any of the recorded findings or on the combined results in the present material.

With regard to the reports of several authors who in view of their observations recommend operation as early as possible (Strahlman 1921, Birgfeld 1928, MacAusland 1931, Meier 1933, Dengler 1938, Nitter 1946, Streli 1955, Barfod & Bierring 1956, Scheibe 1963, Kuhnel 1964, Leuschner & Weickert 1964, Huckell 1965, Herschmann 1965, Mohing 1966, Franke 1966, Gear 1967, Pelzl & Rueff 1969), a longer latency period was expected to give rise to a higher frequency of roentgenologically demonstrable osteoarthritis and unsatisfactory late results. However, in the present material this was not the case, which is in agreement with the reports of other authors (Raess 1930, Spira 1933, Andersson 1934, Efskind 1939, Sjovall 1942, Saugmann-Jensen 1963, Monn 1964, Allegreni & Dell'Orto 1965, Jackson 1968, Tapper & Hoover 1969). The significance of the observed results has been verified statistically in the present series and only in two earlier works (Jackson 1968, Tapper & Hoover 1969).

Nor did the length of the latency period affect the obtained results when the cases with preoperative signs of roentgenologic osteoarthritis or osteoarthritis diagnosed at operation were excluded.

Conclusions

If the clinical and roentgenologic diagnosis of ruptured semilunar cartilage is uncertain, there is no reason to decide on an early operation of an exploratory character The operation can be postponed until the internal derangement of the knee is further manifested, for example, by repeated locking or swelling, since the risk of higher frequency of osteoarthritic changes is not thereby significantly increased.

5. DOES THE TRAUMATIC ORIGIN OF A RUPTURED SEMILUNAR CARTILAGE PLAY ANY PART IN THE RESULTS?

No significant influence on the obtained results was observed when traumatic and nontraumatic ruptures of the semilunar cartilage were correlated with the different findings following a meniscectomy. Some authors have maintained that a higher frequency of unsatisfactory results occurs after operation in cases of traumatic ruptures of the semilunar cartilage (Andersson 1934, Fuss 1951, Streli 1955, Tapper & Hoover 1969). This observation was statistically proved in the series of Tapper & Hoover, but the present results do not verify this conception. Nor do the present results verify Springorum's (1966) view, that less satisfactory results are obtained after meniscectomy if the injury was sustained without any definite trauma. According to Springorum unsatisfactory results in such cases are due to a higher degree of degeneration in both the semilunar cartilage and the joint as a whole.

Conclusions

Whether the injury of the semilunar cartilage was of traumatic origin, or no certain trauma was established, neither of these conditions was found to be of any significance for the late results following meniscectomy.

6. IS THE LENGTH OF THE OBSERVATION PERIOD DECISIVE FOR THE UNSATISFACTORY RESULTS OBTAINED AFTER MENISCECTOMY?

A correlation of the roentgenologic findings at the follow-up investigation with the different groups of observation periods showed a significant increase in the frequency of osteoarthritis with progressing length of the observation period. The correlation is particularly evident when observation periods over and under 24 years are compared. This is in agreement with the findings of other authors who consider that analyses of the results after meniscectomy are representative only if there is a sufficiently long observation period (Nitter 1946, Streli 1955, Saugmann-Jensen 1963, Allegreni & Dell'Orto 1965, Mohing 1966, Jackson 1968). That the frequency of osteoarthritis increases with longer observation period may, to a certain extent, be due to the fact that osteoarthritis is more common in persons of advanced age. A higher frequency of osteo-

arthritis in the operated knee has been found, however, even in elderly patients with a shorter observation period. Moreover, when patients with preoperative osteoarthritis were excluded from the material, the frequency of osteoarthritic changes at the follow-up was still significantly higher in the groups of longer observation period. Furthermore, increasing frequency of osteoarthritis occurred also in the nonoperated knee in patients with a long observation period, but the frequency of osteoarthritis was significantly higher in the operated knee compared with the nonoperated in all the groups of observation period. These findings provide evidence that the increased frequency of osteoarthritic changes observed in patients with a long observation period was an effect of the meniscectomy rather than of the more advanced age of the patients.

Contrary to the roentgenologic findings, subjective complaints, objective findings and combined total results were not influenced significantly by the length of the observation period. Nor have other authors reported that a longer observation period had any effect on the combined late results (Brechling 1942, Barfod & Bierring 1956, Herschmann 1965).

Conclusions

A material of meniscectomized patients is considered representative if there is a sufficiently long observation period. In respect of roentgenologic findings the results of the present investigation confirm this statement. The most accurate conception of the importance of an observation period for the late results after meniscectomy would be obtained, however, if the same material of meniscectomies was followed up on different occasions at intervals, for example of 5—10 years.

7 ARE THE LATE RESULTS AFTER MENISCECTOMY INFLUENCED BY ANY OTHER FACTORS?

a *Preoperative clinical findings:* effusion, lockings, haemarthrosis or a combination of these, have not been shown in this investigation to affect significantly the late results. Barfod & Bierring (1956) stated that especially Anglo-American authors consider that osteoarthritis after meniscectomy is related to preoperative clinical findings rather than to the operation itself. These authors point out, however, that in their own material there was no correlation between preoperative clinical findings and development of degenerative osteoarthritis after meniscectomy.

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Conclusions

The observation that the occurrence of preoperative clinical findings does not influence the late results after meniscectomy supports the conclusions drawn with regard to the latency period, namely, that the late results are not necessarily worse after long postponement before operation.

b. *Preoperative osteoarthritis*, demonstrated roentgenologically or at operation has been shown to give rise to unsatisfactory late results to a significantly greater extent. At the same time it was found at the follow-up investigation that 9 patients who did not show signs of roentgenologic osteoarthritis at the follow-up exhibited such changes preoperatively. In 12 cases, in which osteoarthritis was found at operation, there were no roentgenologic signs of such a condition at the follow-up. Similar findings have been reported by Meier (1933) and Pelzl & Ruëff (1969). A possible explanation of this "regress" of osteoarthritic changes after meniscectomy may be the removal of a disturbing agent from the joint.

Conclusions

Preoperatively demonstrated osteoarthritis either radiologically or at operation cannot be regarded as a contraindication to meniscectomy. But such preoperative findings may require caution before operating, especially on elderly patients.

c. *Postoperative infection* was reported in the patients' records in 4.8 per cent. *Other signs of postoperative complications*, such as effusion in the joint, prolonged for more than 3 weeks, or haemarthrosis were recorded rarely in this series. When they did occur there was no significant deterioration in the late results after meniscectomy. According to Efskind (1939), one could believe that prolonged postoperative effusion would cause a higher frequency of unsatisfactory results. This is not verified by the present material.

Conclusions

Postoperative complications need not necessarily cause a higher frequency of unsatisfactory results.

d. *Postoperative muscular training* in totally meniscectomized patients exerted no significant influence on the late results. However, when patients with preoperative osteoarthritis, diagnosed radiologically or at ope-

ration, are excluded from the material, a significantly higher frequency of osteoarthritis and unsatisfactory combined results is found in patients who did not have postoperative muscular training compared with those who did. A significantly higher frequency of roentgenologic osteoarthritis occurred in patients with total meniscectomy where *postoperative fixation* was applied, compared with those where it was not.[10]) On the other hand, postoperative fixation was not found to have any significant effect on the combined results. The same conditions were prevalent also when patients with preoperative osteoarthritis were excluded from the total material.

Conclusions

The results reported above indicate that physiotherapy and especially muscular training should be introduced as early as possible after a meniscectomy. This is at present a generally accepted routine procedure in the postoperative treatment of meniscectomized patients.

e. Patients who were allowed *to bear weight* on the operated leg first after the 2nd postoperative week showed a significantly higher frequency of roentgenologic osteoarthritis[11]) and unsatisfactory combined results than patients starting weight bearing earlier. Postoperative weight bearing at a later stage may be a routine measure applied by some surgeons. It is probable, however, that patients with preoperative osteoarthritis, diagnosed radiologically or at operation, were not allowed to start weight bearing until later after the operation This assumption is supported by the fact that no significant differences in respect of either earlier or later weight bearing were found when all the patients with preoperative osteoarthritis were excluded from the material of totally meniscectomized knees.

Nelson (1968) reported better results for patients who were allowed to bear weight already after 3—4 days, though with the knee immobilized with a splint for 2 weeks, compared with those who only started weight bearing after 8—10 days.

Conclusions

Starting weight bearing at an earlier or later stage postoperatively did not seem to influence either the roentgenologic findings or the combined results when patients with diagnosed osteoarthritis already at the time of the operation were excluded from the total material.

10—11) see footnote page 41

f. Prolonged postoperative hospitalization seemed to be connected with a higher frequency of unsatisfactory combined results, but the increased frequency was apparently linked with patients who had osteoarthritic changes in the knee already at the time of the operation. Evidently for this reason the hospitalization time was prolonged for such patients.

g. The type of occupation after meniscectomy does not seem to influence the late results. Patients who performed heavy work that involved knee strain did not show higher frequency of osteoarthritic changes in the knee or of unsatisfactory late results compared with patients engaged in lighter work. In this material only 8 patients stated that they had had to change to lighter work because of difficulties with the operated knee. Four of these patients reported at the follow-up that they had only slight subjective complaints.

Raess (1930) and Meier (1933) also stated that the type of work did not influence the postoperative results.

Conclusions

As might be expected, the degree of the occupational strain on the knee after meniscectomy does not appear to affect the results. Heavier work, requiring greater knee strain, did not cause a higher frequency of osteoarthritis or of unsatisfactory combined results. Consequently, there is no reason to advise a patient to change to lighter work after meniscectomy.

h. Patients who were older at the follow-up investigation showed a significantly higher frequency of osteoarthritis, objective symptoms and unsatisfactory combined results compared with younger patients. There was no difference in the frequency of subjective complaints between older and younger patients. In respect of roentgenologic osteoarthritis and objective symptoms the significantly higher frequency observed in older patients was associated with a shorter observation period, which was not the case for the combined results. In the present material the frequency of degenerative arthritis increased with advancing age also in the operated knee. However, the frequency of osteoarthritic changes in all the age groups at the follow-up was significantly higher in the operated than in the nonoperated knee.

Conclusions

It is clear that the older the patient the more liable he will be to osteoarthritic changes in his knees. It appears, however, that a meniscectomized

knee is affected by osteoarthritis to a still greater extent than a non-meniscectomized knee. This has also been pointed out earlier (Jackson 1968).

8. SHOULD A RUPTURED SEMILUNAR CARTILAGE BE PARTIALLY OR TOTALLY REMOVED?

In the present material there were only 21 knees where a partial meniscectomy was performed. These were also classified in the same way as the totally meniscectomized knees, namely, in different groups depending upon the degree of the roentgenologic findings, subjective complaints, objective findings, and in respect of the combined results. When the partially meniscectomized knees were compared statistically with the totally meniscectomized there were no significant differences in the frequency of roentgenologic osteoarthritis, the subjective complaints, the objective symptoms, or the unsatisfactory combined results.

Conclusions

The results obtained in this material did not show any significant differences between partially and totally meniscectomized knees. Consequently, the author considers that in each individual case it should be decided which surgical method is to be preferred.

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Conclusions

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CHAPTER IX

Summary and general conclusions

1. MATERIAL

a. The material of this investigation consists of 480 out of a total of 718 patients who were operated for injuries of the semilunar cartilage during the years 1921—1960 at the Regional Hospital in Linköping, Sweden. Of these 480 patients, who were followed-up personally, and evaluated as well clinically as roentgenologically, 440 were subjected to total meniscectomy and form the main material for this investigation.

b. The mean age of the patients at the time of the operation was for the entire material 31.9 ± 0.46 years and for the followed-up 33.5 ± 0.53 years.

c. The sex distribution for the entire material was, females to males 1 : 7.54, and for the followed-up patients 1 : 7.27.

d. The ratio lateral to medial meniscectomies was for the entire material 1 : 4.43 and for the followed-up patients 1 : 5.08.

e. The ratio left to right operated knee was for the entire material 1 : 1.20 and for the followed-up patients 1 : 1.26.

f. Definite trauma was stated to be the cause of the injury of the semilunar cartilage in 80 per cent both in the entire and in the followed-up material.

Trauma sustained in connection with athletics was reported as the cause of the injury of the semilunar cartilage in 28 per cent.

g. Meniscectomies after a latency period of more than 6 months were performed in 45.3 per cent of the entire material and in 46.8 per cent of the followed-up patients.

h. For 199 cases (41.5 per cent) the observation period was at least 14 years and for 73 cases (15.2 per cent) it was at least 24 years.

2. METHODS

a. *Roentgenologic findings*

When assessing the signs of osteoarthritis present on the radiographies made at the follow-up investigation, the nonoperated knee wes taken as the control. The different signs of osteoarthritis in the operated and the nonoperated knee were summed up and divided into 4 groups in accordance with the degree of osteoarthritis. *Group 0:* no sign of osteoarthritis; *Group I:* signs of *initial* osteoarthritic changes; *Group II: pronounced* osteoarthritis; *Group III: severe* osteoarthritis.

Because of the difficulties encountered in meeting the need of objective evaluation of the radiographies and in order to obtain as safe information as possible from the results of the radiologic study, two senior radiologists were asked to evaluate the radiograms separately without consulting each other. The results of each evaluation were then analyzed separately. Despite the fact that the allocation of the material to the 4 groups of radiologic findings varied considerably in the two evaluations, the results of the statistical analyses were strikingly similar with only very few minor divergencies. This fact has been regarded as indicating a high degree of reliability in the estimation of the roentgenologic findings in the present investigation.

b. *Subjective complaints*

The assessment of the subjective complaints was based on a standardized questionnaire used at the personal interrogation of all the patients. According to the information supplied by the patients concerning their complaints, the different degrees of complaints were allocated to 4 groups. *Excellent:* no complaints, *Good:* only mild complaints; *Fair:* distinct subjective complaints; *Bad:* fairly pronounced complaints.

c. *Objective clinical findings*

The assessment of the objective findings was also based on a standardized investigation form. The frequency of the objective symptoms was substantially less than the frequency of the subjective complaints and the roentgenologic findings. Consequently, the objective findings were divided into only two groups. *Normal:* no, or only slight, objective symptoms. *With findings:* knees with distinct objective symptoms.

d. *Combined results*

Roentgenologic findings, subjective complaints and objective symptoms were combined to form 4 different groups of combined results. *Group Excellent:* none or at most, slight roentgenologic findings, subjective complaints or objective symptoms. *Group Good:* moderate findings. *Group Fair:* evident findings. *Group Poor:* pronounced roentgenologic findings, subjective complaints and objective symptoms.

3. ROENTGENOLOGIC RESULTS

a. A significantly higher frequency of roentgenologic osteoarthritis was shown to occur in the meniscectomized knee compared with the non-operated knee. No statistically significant difference was demonstrated between totally and partially meniscectomized knees, in respect of roentgenologic osteoarthritis. Among total meniscectomies no significant difference was found between medially and laterally operated knees, but a significantly higher frequency for women than for men. The small number of partial meniscectomies makes a detailed statistical analyses of these cases impossible. Totally meniscectomized knees were analyzed for different factors which could possibly promote arthritis.

b. A correlation of the roentgenologic findings for all followed-up meniscectomized patients with *age at time of operation* showed a significantly higher frequency of osteoarthritis in patients meniscectomized when over 41 years compared with those operated when under 41. When all the patients with preoperative osteoarthritis, diagnosed radiologically or at operation, were excluded, there were no significant differences in the postoperative roentgenologic findings between patients operated when over 41 and those operated when under 41.

c. *Latency period,* — the time that elapsed between trauma, or occurrence of symptoms, and operation, — shorter or longer than 6 months did not influence significantly the occurrence of roentgenologic signs of osteoarthritis. Nor were any significant differences observed, in respect of latency periods, between patients meniscectomized after or before the age of 41. Moreover, when cases with osteoarthritis already at time of the operation were excluded, there were not any significant differences in the frequency of roentgenologic osteoarthritis in respect of the latency period.

d. *Trauma* as cause of the rupture of the semilunar cartilage did not show any significant influence on the occurrence of roentgenologic osteoarthritis following meniscectomy.

e. *The length of the observation period* was found to be of significant importance for the occurrence of roentgenologic osteoarthritis in meniscectomized knees. When the observation period was longer, the frequency of osteoarthritis increased; the difference was especially pronounced if knees with observation periods over and under 24 years were compared. If knees with osteoarthritis already at the time of the operation are excluded from the main material of meniscectomies, there was still a significantly increased frequency of roentgenologic osteoarthritis in patients with longer observation period.

f. Furthermore, a significantly higher frequency of roentgenologic osteoarthritis was found to be present at the follow-up investigation, 1) if the patient had roentgenologically demonstrable osteoarthritis prior to operation, 2) if osteoarthritis was found at the time of operation, 3) if weight bearing was started later postoperatively[12]), and 4) if at the follow-up the patient's age was over 61 years, and then especially in connection with a short observation period. With regard to the time when weight bearing was started, no significant differences occurred if all the cases with preoperative osteoarthritis, diagnosed radiologically or at time of operation, were excluded.

g. *Clinical findings prior to operation,* such as lockings, effusion and haemarthrosis or a combination of these, as well as *postoperative complications* — prolonged effusion, haemarthrosis or signs of infection — did not show any significant influence on the frequency of roentgenologic osteoarthritis in the meniscectomized knee.

h. Patients, where *muscular training* was applied postoperatively, developed a significantly lower frequency of osteoarthritis compared with patients who had not received muscular training, if all cases with osteoarthritis at the time of operation were excluded.

In contrast to this, patients where *postoperative fixation* had been applied had a significantly higher frequency of osteoarthritis compared with patients treated without postoperative fixation[13]). But this holds only for all totally meniscectomized patients, and not for those with no preoperative signs of osteoarthritis, where the frequency is lower.

[12]—[13]) see footnote page 41

i. *Postoperative* heavier *work*, which involved also more knee strain, compared with work requiring less knee strain, did not influence significantly the frequency of roentgenologic osteoarthritis in the meniscectomized knee.

4. RESULTS FOR SUBJECTIVE COMPLAINTS

a. When comparing males and females with regard to the different subjective complaints either separately or in groups, women had a significantly higher frequency of subjective complaints than men.

Nor were there any significant differences, with regard to subjective complaints, between partially and totally meniscectomized knees.

b. Contrary to what was the case with roentgenologic findings, there were no significant differences in the frequency of subjective complaints, between totally meniscectomized knees, whether these had been operated when the patient was under or over 41 years.

c. Nor was the length of the *latency period* of any significance for the frequency of subjective complaints.

d. *Trauma* as the cause of rupture of the semilunar cartilage did not have any significant influence on the frequency of subjective complaints after total meniscectomy.

e. The length of the *observation period* was not found to have any significant effect on the subjective complaints.

f. Among other factors, a later start with weight bearing showed a significantly higher frequency of subjective complaints.

5. RESULTS FOR OBJECTIVE FINDINGS

a. The objective findings showed no significant difference in frequency between medially and laterally meniscectomized knees, or between men and women. Nor was there any significant difference between totally and partially meniscectomized knees with regard to the frequency of objective findings.

b. *Age at time of operation* showed a significantly higher frequency of objective findings in patients meniscectomized when over 41 years than in those under 41.

c. *Latency periods* longer or shorter than 6 months did not show any significant influence on the occurrence of objective findings.

d. *Trauma* as cause of the lesion in the semilunar cartilage did not seem to influence significantly the frequency of objective findings after total meniscectomy.

e. The length of the *observation period* did not play any significant role in the occurrence of objective findings.

f. Of the other factors, osteoarthritis at time of operation and postoperative fixation increased significantly the frequency of objective findings after total meniscectomy.

g. Later start with weight bearing and longer postoperative hospitalization showed a higher frequency of objective findings.

h. A higher frequency of objective findings was observed in patients over 61 years at time of the follow-up investigation than in those under 61. This applies especially to patients over 61 at the time of the follow-up who, at the same time, had a short observation period.

6 COMBINED TOTAL RESULTS

a Differences, in the frequency of unsatisfactory combined results, between medially and laterally meniscectomized knees did not prove to be significant, here women showed a significant increase in the frequency of unsatisfactory total results compared with men.

b No significant differences were obtained with regard to the frequency of unsatisfactory combined results when the totally meniscectomized, the partially meniscectomized and the "double-operated" knees were compared

c The frequency of unsatisfactory combined results in totally meniscectomized patients, who at operation were older than 41 years, was significantly higher than that of younger patients. If, however, patients with

preoperative osteoarthritis were excluded from the material, no significant differences were obtained.

d. *Latency periods* over or under 6 months did not have any significant influence on the combined results for the total meniscectomies.

e. The frequency of the unsatisfactory combined results after total meniscectomy in *traumatic* and *nontraumatic* ruptures of the semilunar cartilage was not affected significantly.

f. The length of the *observation period* did not influence significantly the frequency of unsatisfactory combined results.

g. Of other factors which might possibly cause less satisfactory results, the existence of preoperative roentgenologic osteoarthritis and osteoarthritis diagnosed at time of operation deteriorated the combined total results significantly.

h. Preoperative clinical findings, postoperative complications, and postoperative fixation were not found to affect significantly the combined results after total meniscectomy.

i. If postoperative weight bearing was started later, then a significantly higher frequency of unsatisfactory combined results was observed for all the meniscectomized patients. If, however, patients with osteoarthritis at time of operation were excluded from the material no significant differences were found.

j. Postoperative muscular training gave rise to a significantly lower frequency of unsatisfactory results, if the patients who had osteoarthritis at the time of operation were excluded.

k. Patients of advanced age at the follow-up investigation showed a significantly higher frequency of unsatisfactory results.

l. The type of the postoperative occupation was not found to have any significant influence on the combined total results.

7. GENERAL CONCLUSIONS

Degenerative osteoarthritis occurs in a significantly higher frequency in a meniscectomized knee compared with the *nonoperated control knee*.

The frequency of different degrees of roentgenologic osteoarthritis in this investigation was about 10.8 per cent in the operated and 0.9 per cent in the nonoperated knee in the totally meniscectomized patients, and 9.5 per cent in the partially meniscectomized knees.

The *frequency of subjective* complaints and objective symptoms is lower than that of the combined total results. The *frequency of* roentgenologic findings is contrary higher. Apparently the low *frequency of subjective* complaints affect the combined total results in a higher extent than roentgenologic findings do.

Age at time of operation does not appear to influence the results.

A longer *latency period* does not cause worse results.

Trauma as an aetiologic factor for the rupture of the semilunar cartilage does not influence the postoperative results.

Radiological signs of osteoarthritis increase with the length of the *observation period*. This applies especially for observation periods exceeding 24 years.

Existence or absence of *preoperative clinical findings* does not affect the results.

Roentgenologic osteoarthritis prior to operation gives rise to increased frequency of unsatisfactory results.

Postoperative complications need not necessarily imply a worse prognosis with regard to the late results.

Postoperative muscular training gives rise to substantially better results for the subsequent course.

Postoperative fixation of the knee decreases the frequency of late osteoarthritis

Early or late *postoperative weight bearing* does not affect the late results.

The *type of occupation* after a meniscectomy is of no importance for the late result.

Partial resection or total extirpation of a ruptured semilunar cartilage does not influence the late results.

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g. Of other factors which might possibly cause less satisfactory results, the existence of preoperative roentgenologic osteoarthritis and osteoarthritis diagnosed at time of operation deteriorated the combined total results significantly.

h. Preoperative clinical findings, postoperative complications, and postoperative fixation were not found to affect significantly the combined results after total meniscectomy.

i. If postoperative weight bearing was started later, then a significantly higher frequency of unsatisfactory combined results was observed for all the meniscectomized patients. If, however, patients with osteoarthritis at time of operation were excluded from the material no significant differences were found.

j. Postoperative muscular training gave rise to a significantly lower frequency of unsatisfactory results, if the patients who had osteoarthritis at the time of operation were excluded.

k. Patients of advanced age at the follow-up investigation showed a significantly higher frequency of unsatisfactory results.

l. The type of the postoperative occupation was not found to have any significant influence on the combined total results

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Postoperative fixation of the knee decreases the frequency of late osteoarthritis.

Early or late *postoperative weight bearing* does not affect the late results.

The *type of occupation* after a meniscectomy *is of no importance for the late result.*

Partial resection or total extirpation of a ruptured semilunar cartilage does not influence the late results.

References

Aarstrand T.: Treatment of Meniscal Rupture of the Knee Joint. Acta chir. scand 107, 146—157, 1954.

Abrahamsen H : Menisklaesioner. Ugeskr laeg 95, 709—713, 1933

Ahlbäck S.: Osteoarthrosis of the Knee. Acta radiol Suppl 277, 1968

Aleman O. & Friberg S : On Injuries of the Menisci of the Knee-Joint Acta chir scand. 74, 319—360, 1934

Allegreni R. & Dell 'Orto R.: Postumi di asportazione dei menischi articolari del ginocchio. Rilievi clinici ed aspetti radiografici. Z orthop. 102, 180—181, 1966 (Abstract).

Andersson S.: Nachuntersuchung von operierten Meniscusschäden besonders mit Rucksicht auf die Prognose Acta chir. scand 75, 534—546, 1934

Andreesen R : Erfahrungen bei Wiedereroffnung der Kniegelenke nach Meniscusschaden. Arch orthop Unfall-Chir 37, 434—437, 1937

Andreesen R : Meniscusbeschadigungen (Verletzungen und Erkrankungen) bei Sport und Arbeit Ergebn chir orthop 30, 24—128, 1937

Barfod B & Bierring F : Treatment of Lesions of the Semilunar Cartilages Acta chir scand 110, 422—435, 1956

Barta O. & Perjés K : Erfahrungen bei Operation und Nachbehandlung Meniscusverletzter. Zbl Chir 39, 2071—2074, 1965

Bauer G : Diagnostik och behandling av knaledsartros Svenska Lak-Tid 65, 3475—3496, 1968.

Bauer G., Insall J & Koshino T Tibial Osteotomy in Gonarthrosis (Osteo-Arthritis of the Knee) J Bone Jt Surg 51-A, 1545—1563, 1969

Bestle S : Meniskusschaden und Sport Med Klin 50, 283—284, 1955

Birgfeld. Über Dauererfolge nach Meniskusoperationen Zbl Chir 55, 1058—1061, 1928

Brechling S : Resultater efter operativ Behandling af menisklaesion i knaet Ugeskr laeg 104, 426—431, 1942

Burkle de la Camp H Über Meniscusschaden Arch orthop Unfall-Chir 37, 354—368, 1936

Bohler L Behandlung, Nachbehandlung und Begutachtung von Meniscusverletzungen Erfahrungen an 1000 operierten Fallen Langenbecks Arch klin Chir 282, 264—276, 1955

Danielsson L. G. & Hernborg J.: Osteofyter i knäleden — en klinisk och rontgenologisk efterundersökning Svensk Läk.-Tid. 66, 3802—3805, 1969.
Day A. J: Torn Meniscus of the Knee. Harper Hosp Bull 24, 56—58, 1966.
Dengler S: Über Ergebnisse nach Meniskusoperationen. Bruns' Beitr. klin Chir. 167, 449—472, 1938
Efskind L: Über Meniskusschäden Acta chir scand 82, 499—529, 1939.
Fairbank T. J: Knee Joint changes after Meniscectomy. J. Bone Jt. Surg 30-B, 664—670, 1948
Franke J: Arthrosis deformans und Meniskusoperationen Beitr. Orthop Traum. 13, 89—96, 1966
Frising G: Nachuntersuchung der an der orthopädischen Universitätsklinik in Lund der Totalexstirpation unterzogenen Fälle von Meniskusschäden im Kniegelenk. Acta chir scand 67, 377—402, 1930
Frosch L: Zur Rearthrotomie des Kniegelenkes Hefte Unfallheilk 52, 220—223, 1956
Fuss H: Über spontane und traumatische Meniscusschäden Arch. klin Chir 260, 464—483, 1948
Fuss H Spätergebnisse nach Meniskusoperationen (auf Grunde von 100 nachuntersuchten Fällen) Zbl Chir 76, 1184—1192, 1951
Gear M W L: The late results of Meniscectomy Brit J Surg 54, 270—272, 1967
Hagemeyer Fr W Meniskusresektion oder — extirpation? Zbl Chir. 80, 1087—1099, 1955
Hashimoto H, Goto K & Goto T: Observations on the Lateral Meniscus of the Knee Joints Kumamoto Med J 11, 32—41, 1958
Herschmann H Ergebnisse nach Meniskusentfernung Zbl Chir 90, 393—401, 1965
Huckell J R: Is meniscectomy a benign procedure? Canad J Surg. 8, 254—260, 1965
Hübner A Meniskusoperation und Arthrosis deformans Mschr Unfallheilk. 50, 1—5, 1943
Jackson J P Degenerative changes in the knee after meniscectomy. Brit Med. J 2, 525—527, 1968
Jelinek R: Die Totalexstirpation des Meniskus Wien Med Wschr 21, 498—500, 1965
Jonasch E Das Kniegelenk Walter de Gruyter & Co, Berlin 1964
Key E & Strömberg N Über Operationen wegen Meniskusschäden im Kniegelenk Acta chir scand 67, 502—522, 1930
Kromer K Der Verletzte Meniscus Wilhelm Maudrich Verlag, Wien—Bonn 1955
Kühnel G Meniskusverletzungen. Zbl Chir 89, 89—99, 1964
Lagergren K A Meniscus Operations and secondary arthrosis deformans Acta orthop. scand 14, 280—289, 1953
Leuschner H & Weickert H Klinische und röntgenologische Spätergebnisse nach Meniskotomie Z orthop 99, 315—321, 1964
Litchman H M, Silver C M & Simon S D Injuries to the medial meniscus in the aging patient J A M A 196, 178—180, 1966
MacAusland W R Derangements of the semilunar cartilages based on a study of 388 operative cases Ann Surg 93, 649—682, 1931
Magnus G Unsere Stellung in der Meniscusfrage Zbl Chir 65, 2194—2196, 1938
Mandl F Technischer Bericht über 800 Meniskusoperationen J Internat de Chir. 5, 137—146, 1940

References

Aarstrand T.: Treatment of Meniscal Rupture of the Knee Joint. Acta chir. scand 107, 146—157, 1954.

Abrahamsen H.: Menisklaesioner. Ugeskr. laeg. 95, 709—713, 1933.

Ahlbäck S.: Osteoarthrosis of the Knee. Acta radiol. Suppl. 277, 1968.

Aleman O. & Friberg S.: On Injuries of the Menisci of the Knee-Joint. Acta chir. scand. 74, 319—360, 1934

Allegreni R. & Dell 'Orto R.: Postumi di asportazione dei menischi articolari del ginocchio. Rilievi clinici ed aspetti radiografici. Z. orthop. 102, 180—181, 1966 (Abstract).

Andersson S.: Nachuntersuchung von operierten Meniscusschäden besonders mit Rucksicht auf die Prognose Acta chir. scand 75, 534—546, 1934.

Andreesen R.: Erfahrungen bei Wiedereröffnung der Kniegelenke nach Meniscusschäden Arch orthop. Unfall-Chir. 37, 434—437, 1937

Andreesen R: Meniscusbeschadigungen (Verletzungen und Erkrankungen) bei Sport und Arbeit Ergebn. chir. orthop 30, 24—128, 1937

Barfod B & Bierring F.: Treatment of Lesions of the Semilunar Cartilages Acta chir. scand 110, 422—435, 1956

Barta O. & Perjés K: Erfahrungen bei Operation und Nachbehandlung Meniscusverletzter Zbl. Chir. 39, 2071—2074, 1965

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Bauer G., Insall J & Koshino T.· Tibial Osteotomy in Gonarthrosis (Osteo-Arthritis of the Knee) J Bone Jt Surg 51-A, 1545—1563, 1969

Bestle S: Meniskusschaden und Sport. Med Klin 50, 283—284, 1955

Birgfeld. Über Dauererfolge nach Meniskusoperationen Zbl. Chir 55, 1058—1061, 1928.

Brechling S: Resultater efter operativ Behandling af menisklaesion i knaet Ugeskr. laeg. 104, 426—431, 1942.

Burkle de la Camp H: Über Meniscusschaden Arch orthop Unfall-Chir 37, 354—368, 1936

Bohler L.: Behandlung, Nachbehandlung und Begutachtung von Meniscusverletzungen Erfahrungen an 1000 operierten Fallen Langenbecks Arch klin Chir 282, 264—276, 1955.

Strelec J. & Wozelka I: Die durch totale Meniskektomie behandelten Meniskusläsionen die Kniegelenkes Zbl. Chir. 89, 1039, 1964, (Abstract)
Streli R: Spätergebnisse nach partieller Meniscusresektion bei 82 Fällen Chirurg 26, 97—103, 1955.
Stumpfegger L: Wiedereröffnung von Kniegelenken nach Meniscusoperationen. Arch klin Chir. 199, 62—75, 1940
Tapper E. M & Hoover N. W: Late results after meniscectomy. J. Bone Jt. Surg. 51-A, 517—526, 1969
Uebermuth H: Meniscusextirpation, Regeneration und Arthrosis deformans. Chirurg 13, 329—334, 1941.
Weisbach K.: Extirpation oder Teilresektion des zerrissenen Meniscus? Chirurg 14, 207—212, 1942.
Wynn Parry C. B, Nichols P. J. R. & Lewis N R.: Meniscectomy: a Review of 1,723 cases. Ann. phys Med. 4, 201—215, 1958
Zippel H: Meniscusschäden und Meniscusverletzungen Arch orthop Unfall-Chir. 56, 236—247, 1964

Mandl F.: Rearthrotomie nach Meniskusoperationen. Zbl. Chir. 79, 1169—1176, 1954.
McLaughlin J. L.: Injuries to the lateral meniscus of the knee Harper Hosp. Bull. 24, 59—62, 1966.
Meier F.: Resultate nach Meniskektomien. Schw. Med. Wschr. 63, 1019—1022, 1099—1106, 1933.
Mohing W.: Die arthrosis deformans des Kniegelenkes. Springer-Verlag, Berlin, Heidelberg, New York 1966.
Monn E.: Meniskusruptur i Kneleddet. Tidskr. Norske Laegef. 6, 537—538, 1964.
Nelson M. A.: Early ambulation following meniscectomy. Ann. phys. Med. 9, 282—287, 1968.
Nitter L.: Arthrosis in the Knee after meniscectomy. Acta chir. scand. 93, 483—494, 1946.
Pelzl H. & Ruëff F. L.: *Operative und konservative Behandlung der Meniskusverletzungen.* Munch. Med. Wschr. 2, 74—79, 1969.
Perey O.: Follow-up results of meniscectomy with regard to the working capacity Acta orthop. scand. 32, 457—460, 1962.
Raess: Meniskusschäden, ihre operative Behandlung und Dauerresultate. *Veröff* Heeres-Sanit. 85, 97—118, 1930.
Ritchie D. M: Meniscectomy in children Australian and N Z J. Surg. 35, 239—241, 1966.
Rostock P. & Runge H.: Zusammenhang zwischen Meniscusschädigung und *Beruf und* Sport. Arch. ortoph Unfall-Chir. 38, 460—485, 1937.
Rothascher H: Ergebnisse nach vollständiger Meniscusentfernung. Arch klin. Chir. 294, 118—134, 1960.
Saugmann-Jensen J.: Knaets Menisklaesioner. Munksgard, København 1963.
Schaefer H. G: Zur Rearthrotomie des Kniegelenkes, zugleich ein Beitrag zu der Regeneration des Meniskus Zbl. Chir 78, 1048—1054, 1953
Scheibe J.: Spätergebnisse nach Meniscusoperationen Mschr. Unfallheilk. 66, 330—335, 1963.
Schilling H.: Vollständige oder teilweise Meniscusentfernung? Mschr. Unfallheilk. 66, 81—87, 1963
Schilling H: Rearthrotomien nach Meniscusoperationen Mschr Unfallheilk 66, 424—438, 1963
Schilling H: Das sogenannte Regenerat nach Meniscusoperation. Hefte Unfallheilk 81, 107—109, 1965.
Sevastikoglou J.: Diagnostik vid mediala menisskador Nord Med 52, 1047—1048, 1954.
Sjövall H.: Die Spätergebnisse nach totaler Meniscusextirpation Acta orthop scand 13, 153—217, 1942.
Smillie I S.: *Injuries of the Knee Joint 3rd Ed, E & S Livingstone Ltd, Edinburgh* and London 1962.
Spira E.: Über die Diagnose und die Behandlungserfolge bei Verletzungen der Menisken *Brun's Beitr klin Chir 158, 157—170, 1933*
Springorum P W Die totale Meniskusextirpation und ihre Berechtigung Zbl Chir *91, 1265—1269, 1966*
Strahlman L & White J W · Derangement of the semilunar cartilage Observations in seventy-six operative cases J A M A 76, 561—564, 1921

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I. *Müssbichler, H.:* Arteriographic studies of the normal hip in adults; evaluation of methods and vascular findings. *Acta radiol. (Stockh.)* 1970, in press.

II. *Müssbichler, H.:* Arteriographic studies in fractures of the femoral neck and trochanteric region; type and incidence of findings in pre- and postoperative examinations, relation to fracture dislocation and prognostic value. *Angiology* 1970, in press.

III. *Müssbichler, H.:* Arteriographic findings in necrosis of the head of the femur after medial neck fracture. *Acta orthop. scand.* 1970, in press.

In the text these papers will be referred to by their Roman numerals.

CONTENTS

INTRODUCTION

The blood supply of the femoral head has long been the subject of anatomical studies on cadavers and specimens (20, 33, 11, 31, 29, 14, 10, 26, 25). These examinations have shown that the femoral head is supplied by branches of the medial circumflex artery and its posterior collum branch. The supply of the femoral head is maintained mostly by the superior retinacular artery, the termination of the posterior collum branch. The inferior retinacular and ligamentum teres arteries play a smaller part but may in some measure compensate for a disturbance of the circulation in the superior retinacular artery (25). In Fig. 1 the vessels to and around the caput are shown schematically. The arteries are indicated by numbers which are also used in the arteriograms below.

Clinical investigation of the blood supply of the femoral head in living persons was stimulated by the attempt to predict the viability of the head after neck fracture. A reliable prognosis would make possible proper treatment of the fracture in each individual case. A solution to the problem has been sought either by direct demonstration of the vascular pattern of the hip by arteriography or by estimation of the circulatory state of the head carried out with several methods; the best known and/or important ones may be mentioned.

Intraosseous venography (12, 32) is based on the examination of the venous drainage from the femoral head after injection of contrast material into the head. Demonstration of one or several draining veins is presumed to indicate intact arterial supply of the caput, whereas the lack of venous filling suggests arterial damage. *Radioisotopes* are injected intravenously or into the femoral head in order to study the circulation to or from it (31, 6, 15, 7, 13). The circulatory state of the caput is calculated and its viability predicted from the access of the isotope into the general circulation or uptake in

All the tests mentioned, used for prediction of the viability of the caput after neck fracture, are not, however, appropriate for study of the arteries themselves, which is possible by *arteriography*. This seems to be the method of choice for direct studies of the arteries in both normal, unaffected hips and in cases with fracture and femoral head necrosis.

Angiography in unaffected hips has already been carried out to a limited extent by Müssbichler (19), Hipp (10), and Brugger (8). Based on the findings of these examinations, arrested and/or delayed circulation in the posterior collum branch could be disclosed in neck fractures by Mussbichler (19). These findings were later confirmed by other authors (10, 8, 9, 17). Brunner et al. (9) showed additionally a close relationship between arrested circulation and development of femoral head necrosis as well as a relationship between normal circulation and healing of the fracture without necrosis. Femoral head necrosis has also been the subject of angiographic examinations. Mussbichler (19) noted delayed circulation in the posterior collum branch in 3 out of 4 cases examined. Lange and Hipp (16) reported on 6 cases and described a great variety of findings such as smallness, shortness, incomplete filling, and non-filling of the posterior collum branch or the femoral head vessels.

In the above-mentioned angiographic investigations many interesting questions were, however, left unanswered. The vessels of the unaffected hips, only examined as a complement to the studies of the vascular condition in affected hips, were not examined with regard to vascular details. Furthermore, in neck fractures the circulatory lesions were not studied in relation either to the type of dislocation or to reduction of the fracture. Systematic angiographic studies of fractures after nailing have not been carried out either Angiographic studies of patients with pertrochanteric fracture or necrosis of the femoral head are restricted to only a few cases (19, 16, 10) from which, so far, no definite conclusions can be drawn

Recent developments in angiographic techniques, such as the use of catheters, serial angiography with an automatic filmchanger, and the subtraction method (36) have made possible examination of the hip in different positions and have permitted far more reliable demonstration of the arterial circulation. These methods have to a great extent been used in the present investigation, the aims of which may be defined as follows·

the caput. Both intraosseous venography and the radioisotope methods are, as is obvious from the reports of their initiators, associated with a relatively high frequency of false and/or unconclusive results concerning the reliability of the prediction of the fate of the femoral head after neck fracture.

Direct registration of the circulatory state is possible by *intraosseous pressure* measurement *ad modum* Arnoldi and Linderholm (2) and by the use of the *oxygen tension test* devised by Woodhouse (34). Pulseless tracings from the femoral head as well as the lack of a rise in pO_2 in the caput after inhalation of 100 % oxygen is presumed to indicate avascularity. However, no prospective studies of these two methods have been published yet.

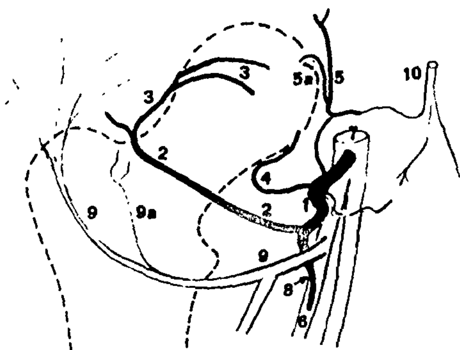


FIG. 1. Schematic drawing of the arteries to and around the femoral head 1 medial circumflex art., 2. posterior collum branch, 3. superior retinacular art., 4 inferior retinacular art., 5 acetabular art., 5 a. ligamentum teres art., 6 deep femoral art.; 7. common femoral art., 8 inferior branch of the medial circumflex art.; 9. ascending branch of the lateral circumflex art., 9 a. its superior branch, 10. obturator artery.

MATERIAL AND METHODS

Angiography was carried out in a total of 167 cases examined with one or several of the following methods:

A. *"General" arteriography* (I, II, III) with injection of contrast material into the common femoral artery in a retrograde direction carried out either through a blunt Seldinger cannula, in 34 cases, or through a polyethylene catheter, in 99 cases (Fig. 2 A).

B. *"Semiselective" arteriography* (I) with injection of contrast material into the common femoral artery in antegrade, i. e. in peripheral, direction. This was achieved either by use of a loop-formed Ödman-Ledin catheter (21), in 26 cases, or a straight polyethylene catheter, in 3 cases (Figs. 2 A', 3 and 7 *lower*). For the application of methods A. and B., the femoral artery was compressed at the thigh with a pressure cuff. The contrast medium (16 and 10 ml Urografin 76 % respectively) was injected for 2—3 seconds.

C. *Selective internal iliac arteriography* (I) with injection of 10 ml Urografin 76 % into the trunk of the internal iliac artery with a loop-formed, red Ödman-Ledin catheter (Fig. 4), in 14 cases; nine of them were part of the case material examined by method A or B.

While methods A. and B. were used for evaluation of the vessels of the hip, C. was used in order to study whether and to what extent the internal iliac artery contributes to the blood supply of the femoral head.

A. To study the vascular pattern in healthy hips with regard to frequency of filling, origin, course, and ramification of the arteries most important for the nutrition of the hip joint and the femoral head in particular (I).

B. To study medial neck and pertrochanteric fractures angiographically with reference to the type of vascular lesion, their incidence, and relation to fracture dislocation, fracture reduction, and osteosynthesis; and furthermore to correlate the vascular findings from fresh and operated fractures with the fate of the caput as regards necrosis (II).

C. To study the type and occurrence of vascular changes in necrosis of the femoral head after medial neck fracture (III).

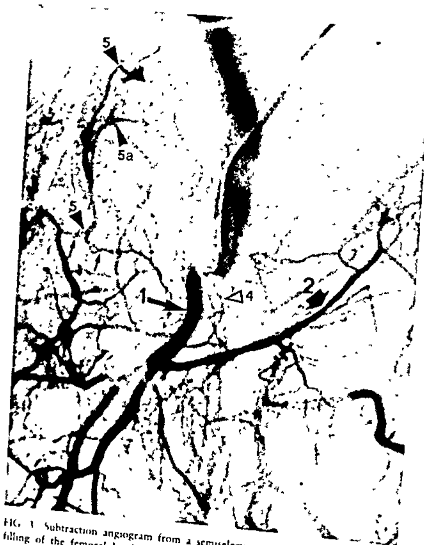


FIG. 1 Subtraction angiogram from a semiselective examination illustrating the filling of the femoral head vessels except the superior retinacular art., the demonstration of which was, for some reason, not possible. Posterior collum branch (2), inferior retinacular art. (4), acetabular (5), and lig. teres art. (5 a) generated by the acetabular branches (small arrows) of the obturator and medial circumflex arts. respectively.



FIG. 2. One case examined with both general (*A*) and semiselective (*A'*) arteriography. In (*A*) gluteal branches (small arrows) are superimposed on the femoral head and its vessels, particularly the superior retinacular artery (3) whereas in (*A'*) the filling is limited to the external iliac art. and its branches only. Posterior collum branch (2) originating in the bifurcation (1) of the medial circumflex artery together with the inferior branch (8); ascending branch of the lateral circumflex art. (9).

In the 34 cases in which a Seldinger cannula was used, 20 ml Dijodon 50 % was injected and 4 exposures were taken over about 12 seconds. The examination with the cannula was performed in a-p projection with the hip in inward or outward rotation. In the remainder, in which a catheter was used, the examination was performed with injections of 10 or 16 ml Urografin 76 %, serial exposures, 1 per second for 15 seconds, and the subtraction method for evaluation of the angiograms.

In order to show the great range of individual variations, the diameters of the most important arteries were measured with the aid of a magnifying glass with a built-in mm scale.

RESULTS

Normal hips (I)

The vessels of the clinically and roentgenologically unaffected hips were studied in angiograms from 106 examinations in a total of 97 cases. Ninety-two were examined with general or semiselective arteriography and 14 cases with selective internal iliac arteriography; 9 of the latter were part of the material also studied with general arteriography.

The present investigation concerned evaluation of the anatomy of those arteries which directly or indirectly participate in the blood supply of the hip joint and of the femoral head in particular. They comprise branches of the medial and lateral circumflex arteries such as the posterior collum branch, the acetabular, ligamentum teres, inferior, and superior retinacular arteries, the ascending branch of the lateral circumflex artery, as well as arterial communications from the internal iliac artery to the femoral head (Figs. 1—7).

The results from general and semiselective arteriography were practically equal as regards the frequency of filling of the femoral head vessels, except for the acetabular artery in which the filling varied somewhat according to the method (see below).

The arteries of the hip known from the studies of anatomists (Fig. 1) could, in principle, be confirmed in living subjects by the present investigation (Figs. 2 and 3). Additionally, the present study revealed great individual variation as regards location of the origin, course and diameter of the vessels and their filling frequency. The most important variations concerned anomalies of the posterior collum branch such as hypoplasia in 3 cases (Fig. 5) and non-filling from the medial circumflex artery in 11 cases (Fig. 6), the latter was frequently found bilaterally. In 2 of these 11 cases, an ectopic origin of the posterior collum branch from the inferior gluteal artery was disclosed (Fig. 7), whereas in the remaining 9 cases the branch was not filled. The superior retinacular and acetabular arteries also varied individually in size and the incidence of their filling. The

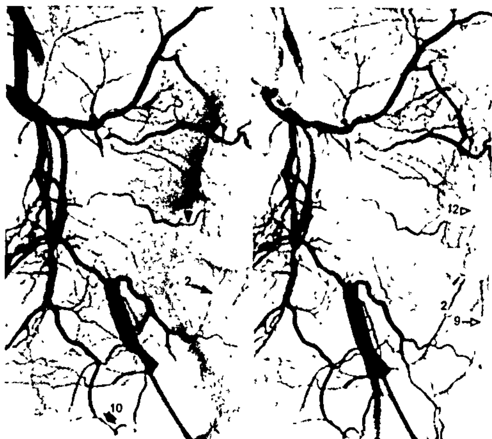


FIG. 4. Subtraction angiograms from selective internal iliac arteriography in different phases. The posterior collum branch (2) fills retrogradely via an anastomosis from the inferior gluteal art. (11), the medial circumflex artery fills via a branch (10) from the obturator artery. Anastomosis between the superior gluteal (12) and lateral circumflex (9) arts.

Complications (I, II, III)

Arteriography gave rise to thrombo-embolism in the femoral artery in one case with advanced atherosclerosis examined with a polyethylene catheter. Embolectomy was carried out and the patient recovered. In another case a transitory spasm of the external iliac artery occurred during catheterization with the loop-formed, red Ödman-Ledin catheter. The examination was interrupted and postponed until the next day, when it was successfully carried out with a polyethylene catheter without incidents. No other complications occurred.

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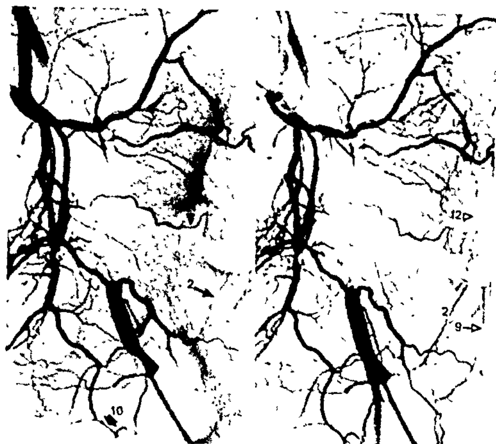


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superior retinacular artery could not be demonstrated in any of the 14 cases in which the posterior collum branch was anomalous. In the remainder (78 cases), it filled with a frequency of 81 %. The incidence of filling of the other femoral head vessels, not influenced by anomalies of the posterior branch, was for the inferior retinacular artery 63 % and for the acetabular artery 27 % and 40 % when examined with semiselective and general arteriography respectively. The ligamentum teres artery was demonstrated in 2 cases only. Selective filling of the internal iliac artery disclosed, in addition to an ectopic origin of the posterior collum branch (2 cases), small anastomoses from the inferior gluteal artery to the posterior collum branch in 3 out of 14 cases (Fig. 4).

Atherosclerotic changes were found in the medial circumflex artery as well as in the posterior collum branch in some cases.



FIG. 7. *Upper* Semiselective arteriogram showing non filling of the posterior collum branch, not derived from the medial circumflex art. (1); its inferior branch (8) is well filled. Soft tissue branches (small arrows) from the lateral circumflex art., ascending branch (9); tip of the looped catheter (K).

Lower Selective internal iliac arteriogram of the same case in different phases and positions, disclosing the ectopic origin of the posterior collum branch (2) from the inferior gluteal artery (11).





FIG. 5. Semiselective arteriography carried out by insertion of a polyethylene catheter (K) into the common femoral artery in a peripheral direction. *Hypoplasia* of the posterior collum branch (2) terminating in small branches (white arrows) far from the trochanteric notch. Medial circumflex art. (1).

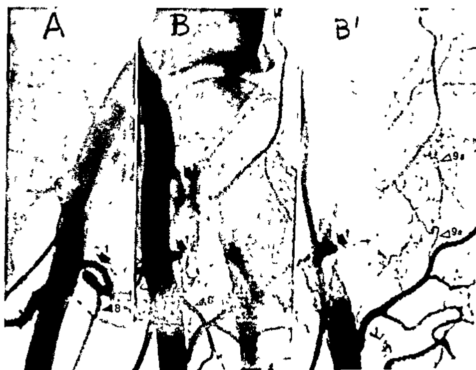


FIG 6. Non-filling of the posterior collum branch due to anomaly It is not derived from the medial circumflex art (1) either in the arthrotic hip (*A*) or in the contralateral, healthy one (*B*) Good filling of the inferior branch (8) which was consistently present Subtraction angiogram (*B'*) illustrates the superior branch (9 a) from the lateral circumflex artery-possibly replacing the posterior collum branch

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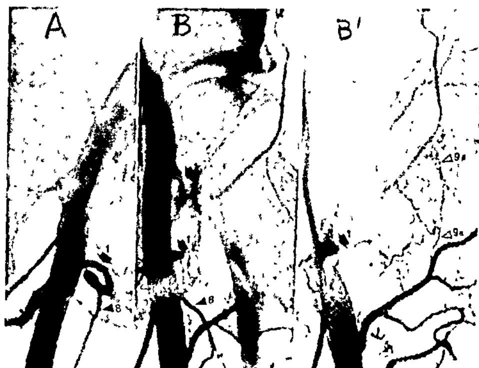


FIG 6 Non-filling of the posterior collum branch due to anomaly It is not derived from the medial circumflex art (1) either in the arthrotic hip (*A*) or in the contralateral, healthy one (*B*) Good filling of the inferior branch (8) which was consistently present Subtraction angiogram (*B'*) illustrates the superior branch (9 a) from the lateral circumflex artery-possibly replacing the posterior collum branch



FIG. 9 *Upper* Serial angiograms of a recent neck fracture in varus position. The circulation in the posterior collum branch is arrested (arrows) and contrast material is pooling in the intact trunk of the vessel
Lower After reduction and nailing the circulation is restored and the posterior collum branch re-filled (*left*, *arrow*), nevertheless necrosis of the femoral head occurred later (*right*)

in it became arrested in the later arterial phase. The superior retinacular artery did not fill in any of the cases when the circulation was disturbed in the posterior collum branch whereas the other femoral head vessels were not affected.

From correlation of the circulatory conditions in the posterior collum branch with the type of dislocation of the fracture, the following results were obtained: (*a*) circulation was disturbed only in

Forty-nine patients with fractures of the proximal end of the femur were examined with general arteriography. The fractures involved the medial part of the neck in 37 cases and the pertrochanteric region in 12. The examination concerned 37 cases with fresh fractures, 27 neck and 10 pertrochanteric, which were examined one to three days after the accident. Twenty-five of them (20 neck and 5 pertrochanteric fractures) were re-examined one to three weeks after nailing, and 12 (10 neck and 2 pertrochanteric fractures) were only studied after the operation.

Of the 37 cases with recent, unreduced fractures, the circulation in the posterior collum branch was normal in 19 cases and disturbed in 18. The latter comprised delayed circulation (Fig. 8) in 3 neck fractures; circulation was arrested (Figs. 9—12) in 12 neck and 3 pertrochanteric fractures. In 2 of the former the circulation was "intermittently" arrested only, i. e. the posterior collum branch was normally filled at the beginning of the arterial phase but circulation

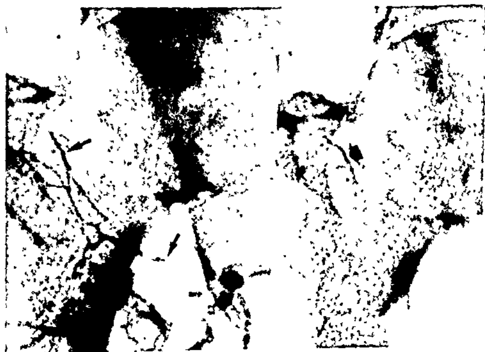


FIG. 8. Serial angiography of a recent neck fracture without dislocation. The posterior collum branch (arrows) is well filled (*left*) but the circulation through it is delayed which is indicated by pooling of contrast medium in its peripheral part (*right*, heavy arrow).



FIG 11 *Upper* Serial angiograms of a recent malrotated pertrochanteric fracture with arrested circulation (heavy arrow) in the posterior collum branch *Lower* After reduction of the malrotation by forced inward rotation of the leg, the circulation normalized and two branches of the superior retinacular artery also filled (arrows)

malrotated recent fractures (the findings concerned 15 neck and 3 pertrochanteric fractures), and (*b*) circulation was normal in 12 neck and 7 pertrochanteric fractures with malrotation present in only 3 and 1 cases respectively. The circulation was not affected by valgus or dorsal angulation up to 30 degrees.

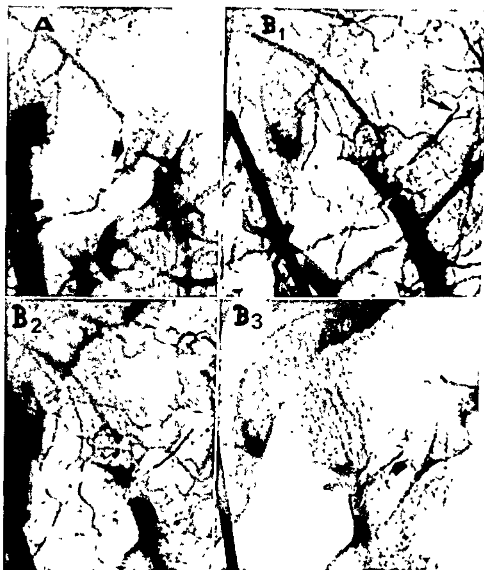


FIG. 10. *A*: Serial angiogram of a fresh, malrotated neck fracture with arrested circulation (arrow) in the posterior collum branch. *B*: Serial angiograms after reduction of the malrotation by forced inward rotation of the leg. Now a complete filling of the posterior collum branch is obtained (*B'*, arrow); however, the circulation is somewhat delayed, visible from the pooling of the contrast material at the end of the arterial phase (*B3*, heavy arrow).



FIG 12 Serial angiogram of a recent, malrotated, pertrochanteric fracture with arrested circulation in the posterior collum branch (*left*, heavy arrow). After reduction and nailing (*right*), the circulation normalized (2) and the superior (3) and inferior retinacular (4) arteries became well filled.



FIG 13 Two cases (*A*, *B*) with pertrochanteric fractures In both cases the posterior collum branch did not fill because of an anomaly This condition should not be misinterpreted as a circulatory disturbance Medial circumflex art (1), inferior branch (8), ascending branch of the lateral circumflex art. (9), branches of the inferior gluteal art (small arrows in *B*)

Reduction of malrotation by forced manual inward rotation of the leg was immediately followed by restitution of the circulation in the posterior collum branch (Figs. 10 and 11). This was noted in 5 cases in which the reduction manoeuvre was successful. Restitution in the posterior collum branch was accompanied by a filling of the superior retinacular artery in 2 cases.

Thirty-seven patients were examined after definitive reduction and nailing; in no case was arrested circulation observed. In the 13 cases with arrested circulation prior to operation, filling of the posterior collum branch was restored to normal in all cases (Figs. 9 and 12). However, in 4 of them, 3 neck and 1 pertrochanteric fractures, the circulation remained delayed.

Forced outward rotation of the leg also caused arrest of the circulation in the posterior collum branch in 2 pertrochanteric fractures even though they had been thoroughly reduced and nailed.

Non filling of the posterior collum branch due to an anomaly was observed in 1 neck and 2 pertrochanteric fractures (Fig. 13).

A follow-up study of 9 fresh, unreduced neck fractures with arrested circulation revealed later development of femoral head necrosis in 7 cases, whereas in the fresh fractures with normal or delayed circulation necrosis occurred in only 1 out of 9 cases. Out of the 24 neck fractures examined angiographically after nailing and followed-up, necrosis developed in 9 cases, in 2 of which the circulation had been delayed in the fresh fracture. In the remaining 15 cases, 1 with delayed and 14 with normal circulation, necrosis did not appear.

The superior retinacular artery was not filled in any of the 11 cases in which necrosis developed, whereas it had filled in 7 out of the 16 cases in which necrosis was not established at follow-up No correlation was found between the incidence of filling of the other femoral head vessels and the ultimate fate of the caput.

Necrosis was not seen to develop in any of the 7 pertrochanteric fractures followed-up. In one of them, however, the circulation in the posterior collum branch was arrested prior to reduction.

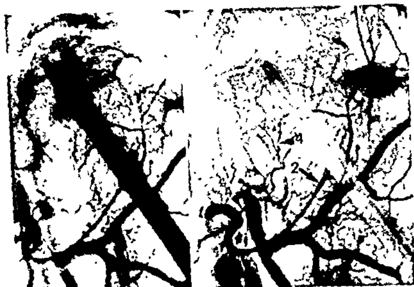


FIG 15 Conventional and subtraction angiograms in necrosis of the femoral head Enlarged inferior retinacular artery (4) hypervascularizing the medial, less involved portion of the caput Medial circumflex art. (1), posterior collum branch (2) with arrested circulation in outward rotation of the leg

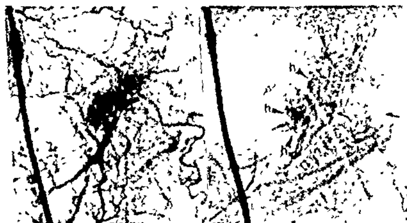


FIG. 16 Subtraction angiograms of a case with necrosis and non united fracture Posterior collum branch (heavy arrow) The fracture area is hypervascularized (h), optimally visible in late arterial phase (*right*) Venous drainage indicated by small arrows

Necrosis (III)

An account is given of the arteriographic findings from 21 cases with necrosis of the femoral head after medial neck fracture. In agreement with previous observations (19), delayed circulation in the posterior collum branch was a frequent and typical finding evident in 13 cases (Fig. 14). Furthermore, the present examination disclosed that the superior retinacular artery did not fill in any of the cases with necrosis, indicating nutritional disturbance of the caput. On the other hand, the inferior retinacular artery was frequently enlarged (Fig. 15) and the acetabular and ligamentum teres arteries were both enlarged and more frequently filled than in the unaffected control hips. Moreover, hypervascular areas were found at the site of the old fracture and the less necrotic, medial portion of the femoral head in 14 cases (Figs. 14—16).

Rotation studies of the leg were performed in 14 cases. In inward rotation, the posterior collum branch was well filled in all cases, but circulation in it was interrupted in 4 cases when the leg was outwardly rotated by force (Figs. 15 and 17). All 4 cases were old, unhealed neck fractures which in the latter instance became malrotated.



FIG 14 Serial angiograms of a case with total necrosis of the femoral head Good filling of the posterior collum branch (2) in which the contrast medium is pooling throughout the venous phase (*right*), vein (v), hypervascular area (h)

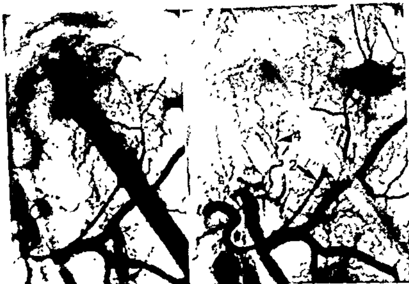


FIG 15. Conventional and subtraction angiograms in necrosis of the femoral head Enlarged inferior retinacular artery (4) hypervascularizing the medial, less involved portion of the caput. Medial circumflex art. (1), posterior collum branch (2) with arrested circulation in outward rotation of the leg.



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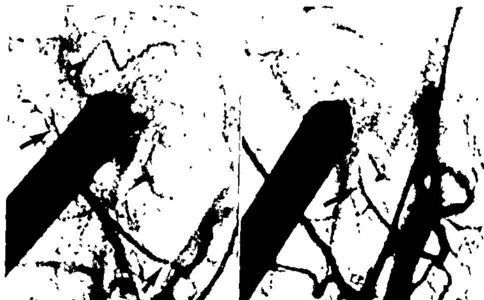


FIG. 17. Serial angiograms of a case with necrosis and unhealed fracture. Normal extension of the posterior collum branch (arrows) in inward rotation of the leg (*left*). The circulation became arrested when the leg was rotated outwardly (*right*, arrow).

DISCUSSION

The vascular supply of the head of the femur has been the subject of earlier angiographic investigations in living persons with healthy hips (19, 10, 8) as well as with neck fractures (23, 19, 10, 8, 9, 17) and femoral head necrosis (19, 16, 10). In these investigations contrast material was usually injected through a long sharp needle into the common femoral artery in a retrograde direction, a convenient method for arteriography of the whole leg used for several decades. Mussbichler (19) used exclusively the blunt Seldinger cannula 205 in order to reduce the risk of arterial wall damage by the sharp tip of the needle. In the present study cannulas have been replaced by catheters, the use of which allows free rotational movements of the hip joint during arteriography. In this way angiograms could be obtained in different projections, which is desirable for accurate and reliable identification of the vessels and for studying the influence of different positions of the leg on arterial circulation. With this procedure a close relationship between malrotation of fractures and arrested circulation in the posterior collum branch could be proved

Earlier angiographic methods were additionally improved in the present investigation by using serial exposures with an automatic filmchanger, permitting better registration of the arteries than was the case with only 3—4 exposures. By injection of contrast material through the loop-formed, red Ödman-Ledin catheter, the vascular filling can be restricted to the external iliac artery and its branches which are responsible for the nutrition of the femoral head. For this reason this method was called "semiselective". The main advantage of this method was the avoidance of filling of the internal iliac artery, the branches of which are usually superimposed on the femoral head vessels. Application of the subtraction method, well established in other fields of angiography, is of great value for

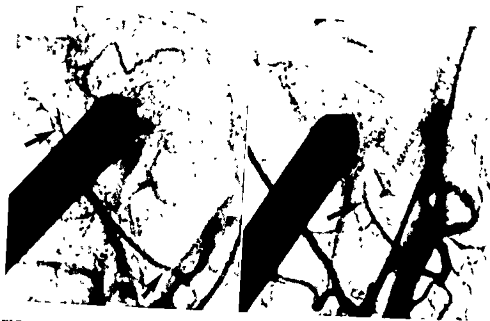


FIG. 17. Serial angiograms of a case with necrosis and unhealed fracture. Normal extension of the posterior collum branch (arrows) in inward rotation of the leg (*left*). The circulation became arrested when the leg was rotated outwardly (*right*, arrow).

DISCUSSION

The vascular supply of the head of the femur has been the subject of earlier angiographic investigations in living persons with healthy hips (19, 10, 8) as well as with neck fractures (23, 19, 10, 8, 9, 17) and femoral head necrosis (19, 16, 10). In these investigations contrast material was usually injected through *a long sharp needle into* the common femoral artery in a retrograde direction, a convenient method for arteriography of the whole leg used for several decades. Mussbichler (19) used exclusively the blunt Seldinger cannula 205 in order to reduce the risk of arterial wall damage by the sharp tip of the needle In the present study cannulas have been replaced by catheters, the use of which allows free rotational movements of the hip joint during arteriography. In this way angiograms could be obtained in different projections, which is desirable for accurate and reliable identification of the vessels and for studying the influence of different positions of the leg on arterial circulation. With this procedure a close relationship between malrotation of fractures and arrested circulation in the posterior collum branch could be proved

Earlier angiographic methods were additionally improved *in the* present investigation by using serial exposures with an automatic filmchanger, permitting better registration of the arteries than was the case with only 3—4 exposures. By injection of contrast material through the loop-formed, red Ödman-Ledin catheter, the vascular filling can be *restricted to the external iliac artery and its branches* which are responsible for the nutrition of the femoral head. For this reason this method was called "semiselective". The main advantage of this method was the avoidance of filling of the internal iliac artery, the branches of which are usually superimposed on the femoral head vessels Application of the *subtraction method, well* established in other fields of angiography, is of great value for

reliable identification of small vessels and, not least, for the recognition of hypervascular areas such as were found in cases with femoral head necrosis.

In previous examinations of healthy hips, the vascular pattern, known from anatomical studies in cadavers and specimens, was to some extent identified angiographically. The examinations of Müssbichler (19) and Brugger (8) revealed in addition that the femoral head vessels could not be demonstrated in all cases examined. These observations are confirmed by the results of the present study, which further disclosed hypoplasia, ectopia, and non-filling of the posterior collum branch. In the last case the posterior collum branch was definitely not derived from the medial circumflex artery. As the latter as well as its inferior branch were well- and consistently filled with contrast medium, non-filling of the posterior collum branch cannot be due to technical errors. This is supported by the fact that this finding was frequently present bilaterally. Non-filling of the posterior collum branch is probably due to an undetectable ectopic origin or replacement of the branch by other sources of blood supply.

The absence of filling of the small femoral head vessels, noted in many cases, may be due to a too low concentration of contrast material and not least, to the smallness of their diameters (0.3 mm is generally accepted as the lower limit of angiographic registration of vessels). These factors should be considered when filling of the femoral head vessels is not obtained.

Selective internal iliac arteriography disclosed only small collaterals to the posterior collum branch in single cases. Filling of the internal iliac artery seems, therefore, of no practical use in angiographic examination of the hip except to demonstrate the acetabular artery and an ectopic origin of the posterior collum branch.

Previous angiographic examinations of femoral neck fractures have mainly been made in an attempt to predict the fate of the femoral head as regards development of necrosis. Rook (23) concluded that "inadequate" or "poor" filling of the femoral, deep femoral, and circumflex arteries indicates reduced blood supply to the femoral head, and predicted a poor prognosis in such cases. The value of this observation, however, has not been checked by follow-up studies. Local disturbances of the circulation in patients with fresh medial neck fractures was demonstrated for the first time by Müss-

bichler (19), and later confirmed by the findings of Hipp (10), Brugger (8), and Maurer et al. (17). No differentiation between circulatory disturbances and anomalies, such as hypoplasia or non-filling of the posterior collum branch, or individual variations in the filling of the femoral head vessels has been made in the studies of these authors. It is obvious, however, that a clear differentiation between a circulatory lesion and normal, individual variations, including anomalies, is of the utmost importance for preventing misinterpretation of the findings.

The diagnosis of arrested circulation should be based on a visible interruption of the flow of contrast material, which usually pools in the intact trunk of the vessel. In the case of anomalous origin, no part of the vessel will be filled (Fig. 13) and in the case of hypoplasia, the vessel is narrow and short but otherwise normal. Atherosclerotic changes can also give rise to misinterpretation. They are not an uncommon finding either in affected or unaffected hips and are characterized by irregularities of the lumen caused by plaques attached to the arterial wall.

Trueta and Harrison (29) suggested from their anatomical studies that the superior retinacular artery is exposed to damage along the neck by varus fractures, whereas valgus fractures do not involve this artery which is the vessel most responsible for nutrition of the femoral head. This should explain the high frequency of femoral head necrosis after varus fractures. Backman (3, 4) contributed to this subject by experimental fractures in specimens of human hips as well as by follow-up studies of patients with neck fractures. He could demonstrate that malrotation of the fracture is responsible for extensive rupture of the superior retinaculum, where the superior retinacular artery runs, as well as for the development of femoral head necrosis. The deleterious role of malrotation upon the circulation to the femoral head could be definitely proved in the present study by angiography of malrotated fractures before and after reduction It seems most likely that the immediate cause of the circulatory arrest is due to kinking or tearing of the posterior collum branch because of the malrotation of the fracture fragments. This assumption is supported by the successful provocation of circulatory arrest in old, unhealed fractures by outward rotation of the leg.

The superior retinacular artery may also be primarily affected, regardless of whether the circulation in the posterior collum branch

is arrested or not. Interruption of the superior retinacular artery has been demonstrated micro-angiographically after neck fracture in specimens of human hips (26). However, angiographic demonstration of lesions confined to the superior retinacular artery or the other femoral head vessels is not possible *in vivo* because of the high frequency of individual variation demonstrated by the present study of normal hips.

Prospective studies of angiographically examined neck fractures have been carried out by Brünner et al. (9). Their results agree with those of the present study, showing a close relationship between the circulatory condition in the posterior collum branch and the occurrence of necrosis. Isolated cases, however, deviated, thus indicating that additional factors may influence the fate of the femoral head: The most important being the *duration* of circulatory arrest. Its protraction is generally leading to arterial thrombosis with irreversible blockage. A similar process may, in the case of neck fractures, involve the superior retinacular artery e. g. the termination of the posterior collum branch.

From experiments on rabbits it is known that the osteoblasts of the femoral head may tolerate an interruption of the blood supply for up to 6 hours (34, 24). Postponed reduction of the fracture-dislocation maintaining circulatory arrest, may thus be responsible for the development of femoral head necrosis, whereas "early" reduction, advocated by several authors (5, 18, 27, 28), may protect or restore normal circulation and avoid the development of necrosis. Optimal effect in preventing necrosis of the femoral head may be expected from fracture reduction performed as an emergency as has been proposed by Strange (28). Forced inward rotation and fixation of the malrotated leg carried out as an emergancy could be an important link in the treatment of malrotated fractures.

Survival of the femoral head may also be helped by pre-existent collateral circulation within the caput, demonstrated microangiographically by Sewitt and Thompson (25) or by extraosseous communications between the trochanteric vessels and the superior retinacular artery (14) and/or between the inferior gluteal artery and the peripheral part of the posterior collum branch — shown in the present study of healthy hips. As one or several of these communications may exist, a reliable prognosis based on the circulatory

condition in the posterior collum branch alone cannot be made in each individual case.

While non-filling of the superior retinacular artery in individual cases is inconclusive, its filling, obtained in 7 fracture cases, seems to indicate viability of the femoral head, as no necrosis of the head was present at follow-up in any of these 7 cases. However, the prognostic value of this observation needs to be proved in a larger material and over a longer period before definite statements can be made.

The mechanism of circulatory arrest in pertrochanteric fractures, in which necrosis usually does not occur, may be different from that in neck fractures The location of the pertrochanteric fracture, far distal and lateral to the posterior collum branch and particularly to the superior retinacular artery, makes it likely that the circulatory disturbance is actually less severe and therefore of a more transient character than in the case of neck fractures.

Delayed circulation in the posterior collum branch without circulatory arrest is thought to indicate impairment of emptying of this artery due to damage to its peripheral part or its main branch, the superior retinacular artery. Delayed circulation was found in 3 cases out of 27 with fresh fractures and in 13 out of 21 with established necrosis. In the latter condition, delayed circulation occurred not only more frequently but was also more pronounced than in recent fractures. This indicates that the degree of the circulatory disturbance progresses simultaneously with the development of necrosis. The consistent absence of filling of the superior retinacular artery throughout the whole necrosis material further emphasizes the nature of the nutritional disorder of the femoral head. Hypertrophy and/or increased filling frequency of the other femoral head vessels as well as the incidence of hypervascular areas point to the occurrence of a re-vascularization process at the fracture site and at the periphery of the necrotic head similar to that demonstrated histologically in humans subjects and experiment animals (26, 22).

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D. Other improvements comprised the use of an automatic film-changer taking 15 exposures over 15 seconds and application of the subtraction method.

The use of blunt Seldinger cannulas and catheters in particular as opposed to the sharp needles used by other authors diminishes the risk of arterial wall lesions. Catheters are to be preferred as they allow studies in different positions of the hip joint, which is desirable for reliable identification of vessels and of conditions of circulatory disturbance. Semiselective angiography with the red Ödman-Ledin catheter showed optimal results as regards identification of the femoral head vessels. The use of serial angiography and the application of the subtraction method further improved the registration of the arterial circulation and identification of vessels.

ad 2 Ninety-two healthy hips were examined angiographically. The findings revealed a great individual variation of the vascular pattern This concerned particularly the posterior collum branch which was hypoplastic in 3 cases and of anomalous origin in 11. Demonstration of the superior retinacular artery in the total material of helathy hips was successful in about 69 % of the cases, of the inferior retinacular artery in 63 %, and of the acetabular artery in 40 % with general arteriography and in 27 % with the semiselective method. The incidence of filling of the other femoral head vessels was not influenced by the arteriographic method used. The existence of small anastomoses between the inferior gluteal artery and the peripheral part of the posterior collum branch was demonstrated by internal iliac arteriography in 3 out of 14 cases. Filling of the internal iliac artery also made possible confirmation of an ectopic origin of the posterior collum branch in the inferior gluteal artery in 2 cases

Ignorance of these angiographic findings in healthy hips must necessarily give rise to misinterpretation of angiograms in fractures, necroses or other affections of the hip

ad 3 A total of 49 cases, 37 with medial neck and 12 with pertrochanteric fractures, were examined. In 37 of them angiography was carried out before nailing (Paragraphs A—C below), 37 were examined after the operation (D), and in 27 cases with medial neck

GENERAL SUMMARY AND CONCLUDING REMARKS

The present angiographic investigation was concerned with the arterial supply of the hip in living persons. It comprised studies of (*1*) arteriographic methods, (*2*) the vascular anatomy of healthy hips, (*3*) the vascular anatomy of neck and pertrochanteric fractures, and (*4*) necrosis of the femoral head after neck fracture. The main results and conclusions of the investigation are summarized as follows:

ad 1. In the demonstration of the arteries of the hip, the following methods were applied:

A. A blunt Seldinger cannula was used in 34 cases in which 20 ml Dijodon 50 % was injected retrogradely into the common femoral artery. In 99 cases, 16 ml Urografin 76 % was injected through a polyethylene catheter into the common femoral or external iliac artery. These types of injection were termed "general arteriography" since, usually, both the external and internal iliac arteries filled.

B. A new catheter technique for semiselective visualization of the arteries of the hips was devised. It consisted of antegrade, peripheral injection of 10 ml Urografin 76 % either through a distally inserted polyethylene catheter (3 cases) or a loop-formed, red Ödman-Ledin catheter (26 cases). The purpose of this type of examination, only used in the normal material, was to avoid retrograde filling of the branches of the internal iliac artery superimposed on the vessels of the femoral head.

C. Selective internal iliac arteriography was carried out in 14 cases in order to study the contribution of this artery to the supply of the hip.

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It is suggested that filling of the superior retinacular artery may indicate maintained circulation to the femoral head. However, its non-filling should in the individual case, not be interpreted as a circulatory lesion. It seems likely that the existence of an efficient collateral circulation, angiographically not demonstrable, may keep the caput alive in individual cases even though the circulation in the posterior collum branch or superior retinacular artery has been or still is arrested. This would explain the avoidance of caput necrosis seen in 2 cases with arrested circulation in the fresh fractures.

Reduction of the malrotation leading to restoration of the circulation in the posterior collum branch, suggests that this procedure should be carried out *as an emergency* in order to shorten the period of circulatory arrest. This may be a *valuable link in the treatment of malrotated neck fractures.*

ad 4 Twenty-one cases of femoral head necrosis after medial neck fracture were examined and associated with the following angiographic findings:

A The posterior collum branch showed delayed circulation in 13 cases.

B The superior retinacular artery was not filled in any case.

C. The acetabular and ligamentum teres arteries showed an increased frequency of filling and the inferior retinacular and acetabular arteries were enlarged, compared with the findings from the contralateral, healthy hip. Moreover, hypervascular areas at the fracture site and the medial, less-involved part of the caput were observed.

The arteriographic findings confirm the general opinion of avascularity of the necrotic femoral head but also show the occurrence of peripheral revascularization

fractures follow-up studies were made (E—H). The findings are listed below (A—G concern the circulation in the posterior collum branch).

A. In recent fractures the circulation in the posterior collum branch was normal in 19 cases and disturbed in 18. The latter condition comprised delayed circulation, 3 cases, and arrested circulation, 15 cases.

B. Circulatory disturbance was exclusively present in fractures which were in varus and dorsal angulation or in dorsal angulation of at least 40°.

C. Arrested circulation was restored to "normal" or "delayed" after reduction of the fracture during the angiographic examination. This was shown in 5 out of 12 cases.

D. After operative reduction and nailing, arrested circulation was not noted in any of the 37 cases examined. However, in 3 neck and 1 pertrochanteric fracture, the circulation remained delayed.

E. Follow-up studies could be performed in a total of 27 neck fractures, 18 of them angiographically examined before fracture reduction and 24 after operative reduction.

F. Femoral head necrosis developed in 7 out of 9 cases of fresh medial neck fractures in which the circulation was arrested before reduction, whereas necrosis was noted in only 1 out of 9 neck fractures with normal or delayed circulation. The probability of committing wrong decisions, according to the sign-test, rejecting the null hypothesis, P (necrosis) = 0.5, is less than 9 % and 2 % respectively.

G. Out of the 24 cases with neck fractures angiographically examined after operation, the circulation was normal in 21 cases and delayed in the remaining 3. At follow-up, necrosis had occurred in 9 cases, in 2 of which the circulation had been delayed and in 7 of which it had been normal.

H. The superior retinacular artery filled in none of the 11 neck fractures which later developed necrosis. It was, however, filled in 7 out of the 16 cases in which necrosis was not established at follow-up.

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REFERENCES

1 *Arden G P* Radioactive isotopes in fractures of the neck of the femur. *J Bone Jt Surg*, 42-B 21, 1960

2 *Arnoldi, C* and *Linderholm, H.* Intraosseous pressures in patients with fracture of the femoral neck, methods and preliminary findings. *Acta chir. scand*, 135 407, 1969

3 *Backman, S* Rotational dislocation of the femoral neck. *Acta chir. scand*, 104 377, 1953

4 *Backman, S* The proximal end of the femur, investigations with special reference to the etiology of femoral neck fractures *Acta radiol. (Stockh)*, Suppl 146, 1957

5 *Bohler, L* und *Ender, J* Huftkopfnekrosen nach der Schenkelhalsnagelung, ihre Haufigkeit und Versuche der Verhutung *Wiederherstellungschir u. Traum*, 1 122, 1953

6 *Boyd, H B* Use of the Geiger counter in estimating the blood supply in the femoral head *J Bone Jt Surg*, 33 B 260, 1951

7 *Boyd, H B* and *Calandruccio, R A* The use of radioactive phosphorus to determine the viability of the head of the femur *J Bone Jt Surg*, 45-A 445, 1963

8 *Brugger, G* Zur Frage des prognostischen Wertes angiographischer Untersuchungen bei medialen Schenkelhalsfrakturen *Mschr. Unfallheilk.*, 66 337, 1963

9 *Brunner, S*, *Christiansen, Y* and *Kristensen, J K* Arteriographic prediction of femoral head viability in medial femoral neck fractures *Acta chir scand*, 133 449, 1967

10 *Hipp, E* Die Gefasse des Huftkopfes, Anatomie, Angiographie und Klinik *Z Orthop*, Bd 96, Ferdinand Enke Verlag, Stuttgart 1962.

11 *Howe, W W* and *Schwartz, R P* A study of the gross anatomy of the arteries supplying the proximal portion of the femur and the acetabulum. *J Bone Jt Surg*, 32-A 856, 1950

12 *Hulth, A* Intra osseous venographies of medial fractures of the femoral neck *Acta chir scand*, Suppl 214, 1956

13. *Johansson, S. H.:* The prognostic value of the radio-iodine test in femoral neck fractures. *Acta Soc. Med. upsalien.*, 69: 64, 1964.

14. *Judet, J., Judet, R., Lagrange, J.* and *Dunoyer, J.:* A study of the arterial vascularisation of the femoral neck in the adult. *J. Bone Jt Surg*, 37-A: 663, 1955.

15. *Laing, P. G.* and *Fergusson, A. B.:* Radiosodium clearing rates as indicators of femoral head vascularity. *J. Bone Jt Surg.*, 41-A: 1409, 1959.

16. *Lange, M.* und *Hipp, E.:* Gefassveranderungen bei posttraumatischen Hufine-krosen. *Z. Orthop.*, 92: 513, 1959/60.

17. *Maurer, H. J., Hoffman, E., Hupfauer, W.* und *Schnabelmaier, H.:* Arteriographische Untersuchungen bei Schenkelhalsfrakturen. *Fortschr. Rontgenstr.*, 110: 703, 1969.

18. *Muller, M. E.:* Zur Reposition und Osteosynthese des Schenkelhalsadduktionsbruches. *Helv. chir. Acta*, 24: 237, 1957.

19. *Mussbichler, H.:* Arterial supply to the head of the femur, an arteriographic study in vivo of lesions attending fracture of the femoral neck. *Acta radiol. (Stockh.)*, 46: 533, 1956.

20. *Nussbaum, A.:* Die Gefasse am oberen Femurende und ihre Beziehungen zu pathologischen Gefassprocessen. *Bruns' Beitr. klin. Chir.*, 137: 332, 1926.

21. *Ödman, P.* Radiopaque polyethylene catheters. *Acta radiol. (Stockh.)*, 52: 52, 1959.

22. *Rokkanen, P* Role of surgical intervention of the hip joint in the ethiology of aseptic necrosis of the femoral head. *Acta orthop scand.*, Suppl. 58, 1962.

23. *Rook, F W* Arteriography of the hip for predicting end results in intracapsular and intertrochanteric fractures of the femur. *Amer. J. Surg.* 86: 404, 1953

24 *Rosingh, G F* and *James, J* Early phases of avascular necrosis of the femoral head in rabbits *J Bone Jt Surg*, 51-B. 165, 1969.

25 *Sevitt, S* and *Thompson, R G.* The distribution and anastomoses of arteries supplying the head and neck of the femur *J Bone Jt Surg*, 47-B 560, 1965.

26 *Sevitt, S* Avascular necrosis and revascularisation of the femoral head after intracapsular fractures, a combined arteriographic and histological necropsy study *J Bone Jt Surg*, 46-B 270, 1964

27 *Seyforth, H* und *Schroder, H.* Über die Spatfolgen nach Schenkelhalsfraktur, insbesondere Schenkelhalspseudarthrosen *Bruns' Beitr klin. Chir*, 197 315, 1958

28 *Strange, F G S T Clair* *The Hip* William Heinemann Medical Books Limited, London 1965

29 *Trueta, J* and *Harrison, M H M* The normal vascular anatomy of the femoral head in adult man *J Bone Jt Surg.*, 35-B: 442, 1953.

30. *Tucker, F. R.* Arterial supply to the femoral head and its clinical importance. *J Bone Jt Surg*, 31-B 82, 1949.

31. *Tucker, F R.* The use of radioactive phosphorus in the diagnosis of avascular necrosis of the femoral head. *J. Bone Jt Surg*, 32-B· 100, 1950.

32. *Vestby, G M* Percutaneous intraosseous venography through the hip nail in fractures of the femoral neck, report of a new method and preliminary results. *Invest radiol*, 2 213, 1967.

33. *Wolcott, W. E.* The evolution of the circulation in the developing femoral head and neck, an anatomic study *Surg Gynec Obstet.*, 77. 61, 1943.

34. *Woodhouse, C F* An instrument for measurement of oxygen tension in bone *J Bone Jt Surg*, 43-A 819, 1961.

35. *Woodhouse, C F* The prevention of avascular necrosis. *J. Bone Jt Surg*, 49 B 608, 1967

36. *Ziedses Des Plantes, B G* *Subtraction* Thieme Verlag, Stuttgart 1961.

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With a slightly bad conscience but a truly warm heart, I want to thank my family for their self-denial and patience.

As a member of Professor A. Langenskiöld's research team, I have received support from the Sigrid Juselius Foundation and the Scientific Fund of the Invalid Foundation.

Helsinki, April 1970

Tapio Videman

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CONTENTS

This article is based on earlier investigations, which have been reported in the following papers:[1]

I: *Videman, T.* (1970) An experimental study of the effects of growth on the relationship of tendons and ligaments to bone at the site of diaphyseal insertion. Part I: Experiments with ^{35}S-sulphate and oxytetracycline. *Ann. Chir. Gynaec. Fenn. 59*, 9—21.

II: *Videman, T.* (1970 An experimental study of the effects of growth on the relationship of tendons and ligaments to bone at the site of diaphyseal insertion. Part II: Determination of growth patterns and inhibition of displacement using metal markers. *Ann. Chir. Gynaec. Fenn. 59*, 22—34.

III: *Videman, T.* (1970) An experimental study of the effects of growth on the relationship of tendons and ligaments to bone at the site of diaphyseal insertion. Part III: Autoradiographic study with ^{3}H-thymidine of the insertion area of the tendon of the pectineus muscle *Ann. Chir. Gynaec. Fenn. 59*, 35—41.

1) A preliminary report of the results of the study was presented on October 5, 1967 (A Langenskiold & T. Videman)

CONTENTS

INTRODUCTION

During normal longitudinal growth in the metaphysis of a tubular bone, tendinous and ligamentous insertions maintain their positions relative to the increasing size of the bone. This means that the displacement of the site of insertion in regard to the central part of the diaphysis does not depend directly on the longitudinal growth of the metaphysis between the insertion site and the epiphyseal plate (Figs. 1 A and B)

The mechanism of the displacement of the sites of these insertions is the subject of the present study. Displacement is seen most distinctly in such diaphyseal insertions where a clearly demarcated bundles of collagenous fibres penetrate the bone. When a tendon or ligament only inserts itself into the periosteum, this displacement is associated with the relation between the growth mechanism of the periosteum and diaphysis (*Warwick & Wiles* 1934), but this problem is outside the scope of the present study.

The name Sharpey's fibres is often used in studies of the structure of the insertion areas According to the current definition, Sharpey's fibres anchor tendons and ligaments to bone (*Ham* 1965) *Schneider* (1956) defines the term differently: Sharpey's fibres do not attach tendons to bones, but fix only the periosteum to the bone, while »tendon fibres» (Sehnenfaser) anchor the tendons and ligaments to the bone The formation of bone at the site of insertion was termed »tendinous osteogenesis» (tendinöse Osteogenese) by *Biermann* (1957) to emphasize that tendinous tissue does not simply calcify, but that tendinous bone is being formed by gradual differentiation.

The displacement of epiphyseal insertion in relation to the diaphysis is a direct consequence of the longitudinal growth in the epiphyseal plate and is therefore not dealt with in the present work. Slight displacement of these insertions in relation to the epiphyseal nucleus takes place and the collagenous fibres remain in the bone during growth (*Schneider* 1956)

displacement of the tendon insertions in relation to the central part of the diaphysis during growth (Figs. 1 A and B) has not previously been studied. The growth of the insertion areas can be studied in relation to cells, bone matrix, connective tissue surrounding the tendon and growth disturbances.

^{35}S-sulphate is a suitable medium for autoradiographic studies of the formation of the ground substance of tendons, ligaments, bone matrix and cartilage tissue i e, all possible tissues at the site of insertion The exact chemical composition of the radioactive compound in the insertion areas is not known in detail, but the stages of incorporation of ^{35}S-sulphate in the organism are relatively well-known (sulphated glycosamino glycans) *Dziewiatkowski* 1951, *Jackson* 1953, *Engfeldt & Westerborn* 1960, *Mancini et al.* 1961, *Brondolo & Randelli* 1962, *Crane* 1962) In practice, ^{35}S-sulphate can be used to label only the organic matrix of bone, whereas oxytetracycline can be used to label the mineral component of bone (*Ibsen & Urist* 1962) When this antibiotic is administered to growing animals, it is deposited in bone in connection with the ossification process (*Milch et al.* 1957). Because tetracyclines give a yellow fluorescence in ultraviolet light (*Saltzman* 1950), they can be used as bone label

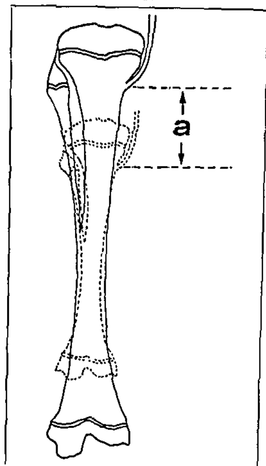
Another technique for studying the mechanism of growth of tendon and ligament insertions is by disruption of normal growth. Fixation of a metal wire in the metaphysis between the insertion area of a tendon (or ligament) and the epiphyseal plate, inhibits the normal displacement of the site of insertion.

Still another technique of study is based on the fact that cells in the premitotic S-phase incorporate ^{3}H-thymidine and that the labelled daughter cells can then be identified autoradiographically even after several subsequent mitoses.

MATERIAL AND METHODS

Four different methods (see below 1—4) were used for the studies of the growth mechanism at the site of insertion of tendons and ligaments

1) *^{35}S-sulphate.* A total of 47 rabbits aged from 9—210 days at the time of administration of the labelled substance were used for the autoradiographic studies ^{35}S-sulphate was given in a single intraperitoneal injection, 1—5 μCi per gram of body weight to each animal. The rabbits were killed 1.2 hours—60 days after the injection. The



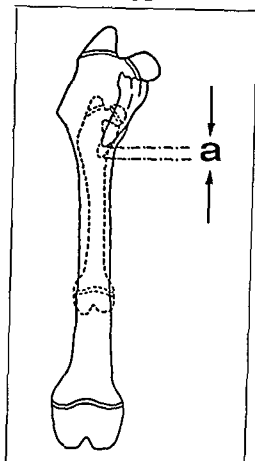


Fig. 1 A: Contour drawings of the rabbit's tibia during two different stages of growth. The tibia *grows 57 per cent from the proximal epiphyseal plate and* 43 per cent from the distal plate. The shape of the tibia at the younger stage is denoted by the broken line. *The contour drawn in full shows a later stage when the length of the tibia had increased by 70 per cent compared to the younger* stage. The displacement of the site of insertion of the medial collateral ligament during the period of growth from the first stage to the second is denoted by *a*.

Fig. 1 B: Contour drawings of the femur of a rabbit at two stages of growth The shape of the femur at the initial observation is denoted by the broken line. *a* denotes the distance which the insertion site of the tendon of the pectineus muscle is displaced in relation to the central part of the diaphysis during growth of the bone from the size at initial observation until the size shown by the fully drawn contour Note that 30 per cent of the longitudinal growth of the femoral diaphysis takes place at the proximal metaphysis.

The results mentioned above were obtained chiefly by histological studies, and there thus seemed reason to check them by autoradiographic studies. These studies with ^{35}S-sulphate have established that substances of the *periosteum* are retained in the bone during the growth process (*Amprino 1955*). *However, the actual mechanism of the*

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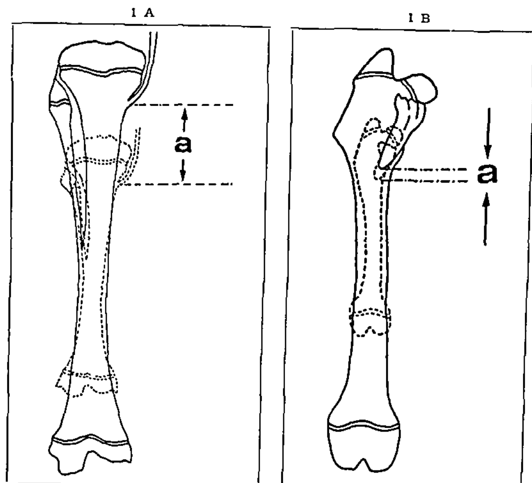


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2) *Oxytetracycline* (Terramycin®, Pfizer) studies were also performed, giving a single injection, 50 mg/kg of body weight, to 15 rabbits aged from 14—28 days. The rabbits were killed within 4—26 days of administration of the antibiotic. The techniques for examination of the bones and for photography were those used by *Puranen* (1966) and *Karaharju* (1967).

3) In the experiments with *implantation of metal markers*, 60 rabbits were used *whose ages ranged from 11—40 days at the time of operation.* Twenty-nine rabbits into which no metal markers were fixed served as the control group. Indian ink marks were used in the ligaments of some animals instead of or in addition to the metal markers. For both the metal markers and the Indian ink marks, the method employed was essentially that used by *Crawford* (1950 and 1954).

Metal markers were used in order to follow the changes by radiography. The animals were killed 11—221 days after the operation. The tendons and ligaments were carefully dissected and the location *of the metal markers was verified. The overall length of the bones* (from proximal epiphyseal plate to distal epiphyseal plate = l,) and the distance of the metal markers from one another and from the epiphyseal plate were measured from the radiographs. The measurements of 21 rabbits were treated mathematically and statistically by a digital computer (IBM 1620) at the Computing Centre of the University of Helsinki. Growth curves and specific growth rates were determined *mathematically from measurements obtained from the radiographs* The statistical means of these parameters were computed.

After fixation in 10 per cent neutral formalin and decalcification in five per cent nitric acid, the specimens were embedded in paraffin wax, sectioned at 10 μ and stained with Weigert's haematoxylin van Gieson.

4) Twenty-two rabbits whose ages ranged from 7—18 days at the time of administration of the radioisotope were used for the experiments with *³H-thymidine*. Each animal received 1.3—4 μCi per gram of body weight of ³H-thymidine in a single intraperitoneal injection. The animals were killed at intervals of two hours to five days after the thymidine administration. The bone and tendon were dissected as a unit immediately after killing and the tissues were fixed in 10 per cent neutral formalin and decalcified 5—15 days in a 32 per cent solution of EDTA. The specimens were embedded in paraffin wax, sectioned at five μ and cleared in xylol. Autoradiographs were prepared by the stripping film technique (Kodak AR 10). After exposure times of 1—3 months, the films were processed in Kodak D 19b developer and acid fixer and the cells were stained with methylene blue The insertion areas were photomicrographed (magnification x 100) from these sections and the labelling of every nucleus seen in the photograph was surveyed at x 1000 magnification under a microscope. All labelled nuclei were marked with Indian ink in the photograph because from the photograph at this magnification alone it was not possible to distinguish reliably a non-labelled nucleus from a faintly labelled nucleus The longitudinal section of the insertion region of the tendon of the pectineus muscle was divided into five areas as shown in Fig 6 For each area, the labelling index (p) was determined from the formula:

$$p = \frac{s_i}{a_i \cdot n_i}, \text{ where}$$

s_i - number of autoradiographically positive cells in area i,
a_i = size of area i (measured by planimeter from the photograph),
n_i = total cells counted in area i (for the determination, the microscopic image was superimposed with 25 points arranged as in the Zeiss Intergrating Eye-Piece I)

RESULTS

1) *Incorporation of ³⁵S-sulphate:* Fig 2 summarizes the results obtained from the ³⁵S-sulphate autoradiographs of the pectineus tendon insertion area Two hours after administration of the labelled sulphate, the radioactivity is strongest in the insertion, periosteum, tendon and bone marrow which has not been marked at all in Fig 2 At the site of insertion the radioactivity does not extend to the bone and there are no distinct differences in labelling intensity among the different areas

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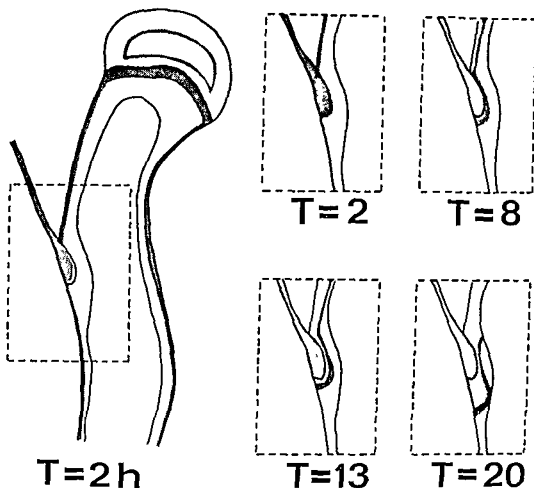


Fig. 2: Schematic summary of the results from autoradiographic studies Outlines have been drawn for the proximal end of the femur and the tendon of the pectineus muscle with its insertion. Radioactivity is denoted in grey Two days *after the administration of the isotope the bone at the insertion region displays a* very narrow radioactive area which remains in the bone Twenty days after the injection, a radioactive zone is seen in the bone below the tendon-bone boundary of the insertion area. There is a very faintly radioactive area between this zone and the tendon-bone boundary The exposure times were chosen to show the most radioactive areas as equally dark in all five phases (h = hours, other figures days)

of the region of insertion. However, two days after the administration of the radioisotope an essential change occurred in the localisation of the radioactivity and there was labelling in the bone adjacent to the tendon-bone boundary of the insertion area. Eight days after the *administration of ^{35}S-sulphate, a weakly radioactive area could be noted* in the tendon-bone boundary. It was clearly distinguished from the more strongly radioactive tendon and bone. The change is obvious when this phase is compared with the preceding phase Intensity of

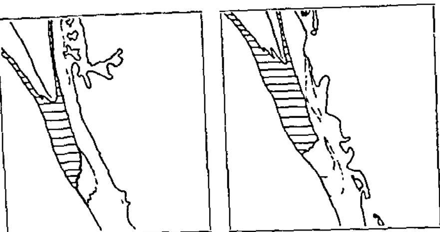


Fig. 3: Diagram of tetracycline studies The grey shading represents the yellow fluorescence of the distal insertion area of the pectineus muscle of rabbit femur The animal was given oxytetracycline four days before it was killed (left) In the picture on the right, the rabbit was given antibiotics 25 days before it was killed, and there is non-fluorescing bone between the tendon-bone borderline and the fluorescing bone.

labelling in the photographs of the different phases of this study cannot be directly compared as the exposure times had to be varied in relation to the time from the administration of the labelled substance (cf. *Langenskiold et al* 1967).

The changes in labelling pattern in the early stages became more pronounced and, by 13 days after the administration of the isotope, the labelling was most prominent in the bone bordering the tendon insertion This radioactive zone was farther from the tendon-bone boundary than in the previous phase The tendon-bone boundary and the bone close to this area were very weakly labelled. Radioactivity in the actual insertion and in the tendon was moderate. At later stages after the administration of ^{35}S-sulphate, the strongly radioactive zone in bone was more distal from the tendon-bone boundary.

2) *Binding of oxytetracycline to the bone*: Fig. 3 is a drawing of longitudinal section made through the insertion of the tendon of the pectineus muscle Four days after the administration of the antibiotic, fluorescing bone (the grey areas in Fig. 3 represent bone that fluoresces yellow in ultraviolet light) is seen on the distal side of the site of insertion in a narrow zone close to the tendon-bone boundary. Fluorescing bone is also seen subperiosteally on the proximal aspect of the insertion. Three weeks later, the fluorescing zone was still visible, but non-

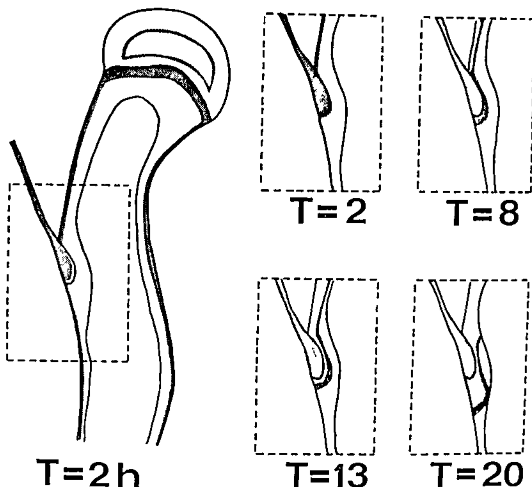


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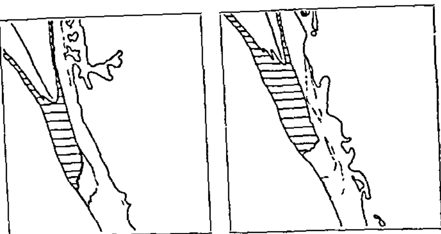


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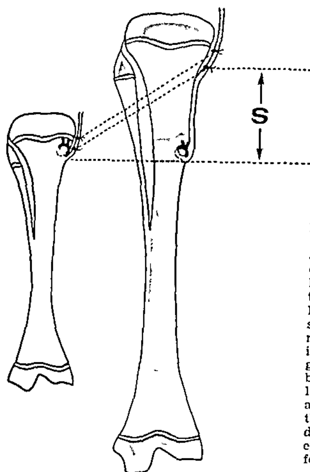


Fig. 4: Contour drawings of the rabbit's tibia during two different *stages of growth At the stage seen* on the right it is about 70 per cent larger than at the stage immediately postoperatively seen on the left. The growth of two different segments of the ligament are marked with dotted lines The insertion segment displaying the greatest relative growth is denoted by *s*. The growth of the rest of the ligament is interstitial, which accounts for the displacement of the metal markers in the ligament *downwards in relation to the* epiphyseal plate New tissue formed is indicated by light areas.

fluorescing bone could be observed between it and the connective tissue of the insertion.

3) *Implantation of metal markers:* When a metal wire loop was *fixed in the bone between the site of insertion of the medial collateral* ligament and the proximal epiphyseal plate of the tibia, the ligament insertion remained at its original site (Fig 4) and the ligament grew in length corresponding to the length of the new part of the diaphysis formed between the marker and the epiphysis The histological sections of the medial collateral ligament of the knee (Figs. 5 A and B) showed that the ligament lay on the surface of the periosteum to which it was partially attached. The diameter of the lengthened ligament was uniform from the level of the epihysis to the metal marker and the ligament *was attached to the diaphysis just distal to the marker* *In* six of 51 rabbits, the tendon or the ligament was inserted partially and in three entirely on the epiphyseal side of the metal marker in

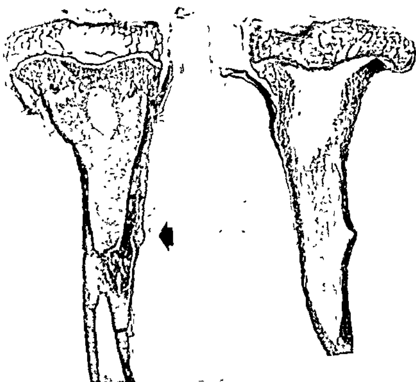


Fig. 5 A (histological sections) Section from the proximal end of the tibia, the abnormally long medial collateral ligament runs along the right edge of the section The location of a metal wire which had arrested displacement of the site of insertion is indicated by the arrow

Fig 5 B Normal insertion of the ligament on the left edge of the control sections

the bone In all cases the insertion was more distal from the epiphysis than in the controls

»Insertion segment» (*s* in Fig 4), refers to the distance between the metal markers in the bone and in the tendon (or ligament) The increase in the length of the insertion segment was 75 2 ± 2 9 per cent of the increase in the metaphyseal length during growth

In the control group, the displacement of the insertion site referable to the central part of the diaphysis was compared to the increase in the metaphyseal length during growth. The mean result was 74 8 ± 0 5 per cent The rate of displacement of the insertion site and the rate of growth of the »insertion segment» were thus 74 8 and 75 2 per cent

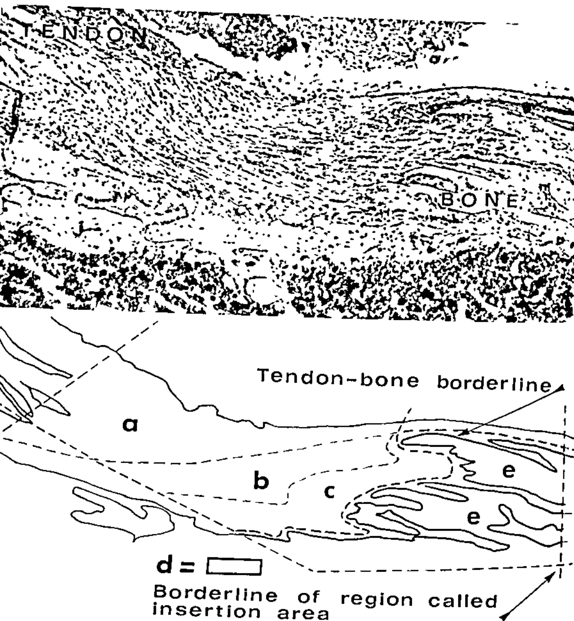


Fig. 6: Histological section (top) of the area of insertion of the pectineus muscle in the femur. The tendinous fibres run from the upper left corner of the microphotograph down to the right There is bone on the right and bone marrow in the lower part of the picture.

The contour drawing shows how the region of the insertion area in the upper photograph was divided into five areas The tendon-bone boundary is drawn with continuous lines The broken line between areas *a* and *b* is a continuation to the boundary between the fibrotic and osteogenic layers of the periosteum Area *d* (shaded in the picture) skirts the bony trabeculae The zone between areas *a* and *d* has been divided by halving the distance of the above boundary lines at each point. Bone is denoted by *e* The limits of the insertion area are drawn in straight broken lines The line down to the middle (on the left) is parallel to the tendinous fibres, but the other limits are somewhat arbitrary

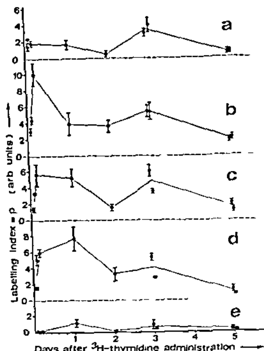


Fig. 7: Graphic representation of the time course of the labelling index in the different areas, *a*, *b*, *c*, *d* and *e*, of the tendon insertion area (cf. Fig 6) The curves are based on results calculated from 64 autoradiographs Each point represents the mean ± SD of different specimens from one rabbit.

of the rate of growth of the metaphysis These percentages were not statistically different.

4) *Incorporation of ^{3}H-thymidine*· The longitudinal section of the insertion region of the pectineus muscle was divided into five areas (*a*, *b*, *c*, *d*, and *e* in Fig 6) and the labelling index (p) of each area was calculated. Fig 7 illustrates the labelling index of areas *a*, *b*, *c*, *d* and *e* as a function of time The cells in the DNA synthesis phase were located chiefly in areas *b* and *d* judging from the preparation where the labelled cells had not yet divided (e g. 2 3 hours after the injection) One day after the administration of the thymidine, labelled cells were numerous in area *c*, as well. After five days, the number of autoradiographically positive cells was decreased in areas *b*, *c* and *d*, but distinctly increased in area *e*, i e, in bone.

The following is a summary of the changes seen in each area.

Area *a* Labelling index in the distal part of the tendon of the pectineus muscle, i e, in area *a*, remained on the whole unchanged and there was no definite peak in the curve

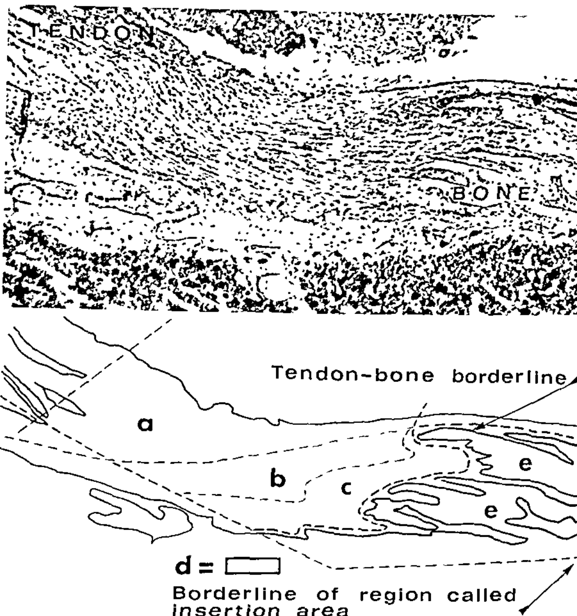


Fig. 6: Histological section (top) of the area of insertion of the pectineus muscle in the femur. The tendinous fibres run from the upper left corner of the *microphotograph down to the right There is bone on the right and bone marrow* in the lower part of the picture

The contour drawing *shows how the region of the insertion area in the upper* photograph was divided into five areas The tendon-bone boundary is drawn with continuous lines *The broken line between areas a and b is a continuation* to the boundary between the fibrotic and osteogenic layers of the periosteum *Area d (shaded in the picture)* skirts the bony trabeculae The zone between areas a and d has been divided by halving the distance of the above boundary lines at each point. Bone is denoted by e The limits of the insertion area are drawn in straight broken lines The line down to the middle (on the left) is parallel to the tendinous fibres, but the other limits are somewhat arbitrary

stronger radioactivity of the environment, could be seen on the tendon-bone boundary.

These results may be explained as follows: the rate at which tendinous tissue is produced in the insertion area is not the same in all parts of the area, but there is a zone in which the connective tissue is synthesized more rapidly than elsewhere in the environment. Part of the connective tissue formed at the time of administration of ^{35}S-sulphate is incorporated in the bone and, following this, new connective tissue is laid down, especially in the zone of most rapid growth, which is not radioactive. Another possible explanation is that the radioactive connective tissue is in soluble form along the tendon-bone boundary and the pale zone is thus an artefact. However, the results using ^{3}H-thymidine show that there are zones in the insertion region which have varying population kinetics, although the boundaries between them are not sharp Relatively few mitoses take place in zone c compared with the adjoining zones It is thus possible that on moving from area b to area c cellular proliferation diminishes and synthesis of the intracellular substance increases Hence, the insertion area can be compared functionally with the epiphyseal plate in which it is possible to distinguish between, e g , a cell proliferation layer and a layer of mature cells which synthesize the intercellular substance

In addition, population kinetic studies established that the boundary between the tendon itself and the insertion area runs between zones *a* and *b* The growth in area *a* was diffuse, as in the description of tendon growth given by *Crawford* (1950) and *Hughes* (1956) Also, the lengthening of the distance between the metal markers in the medial collateral ligament corresponds with this diffuse mode of growth of tendons The results of the metal marker experiments shown in Fig 4 are in good agreement with the results obtained by other methods. Longitudinal tendon growth in the insertion is proportional to the bone growth originating from the epiphysis, and the most rapid tendon growth obviously occurs in zone *c* (Fig 6) close to the tendon-bone boundary. During normal growth the insertion area of the tendon shifts in regard to the central part of the diaphysis together with the formation of tendon, new bone originating along the tendon-bone boundary. Substances of the tendon tissue were retained in the bone during the growth process

Area *b*. There appeared to be a peak at about five hours in area *b*.

Area c. Precise determination of the peak in the labelling index of the cells in area *c* was difficult, but the peak fell mainly within the region of half a day and certainly at a later time than in area *b*.

Area *d*. This area, the insertion region adjacent to the bone trabeculae, had a peak at one day.

Area e. In area e, i.e., within bone, no distinct peak was noted; the slope of the time course curve was initially ascending, but descended slowly thereafter.

DISCUSSION

The autoradiographs obtained after labelling with ^{35}S-sulphate showed that the radioactivity originally taken up by the connective tissue cells of the insertion area is deposited in the bone and appears farther from the site of insertion as the bone grows. Therefore, the tendon-bone boundary of the region of insertion moves further from the central part of the diaphysis because of the interposition of newly-formed, unlabelled bone. It should be noted that 95 per cent of the ^{35}S-sulphate injected is excreted within five days in the urine and stools, and no appreciable radiosulphate is present in the blood 1—2 days after an intraperitoneal injection (*Dziewiatkowski* 1949). It has been demonstrated chromatographically that in slices of cartilage about 90 per cent of the total radioactivity is in chondroitin sulphate (*Dziewiatkowski* 1962). It is important to note, however, that the results obtained in the present study only reflect the behaviour of ^{35}S-containing substances which are not removed from the tissue by the preparative techniques used.

The pictures obtained using the tetracycline technique confirm the findings of new bone formation along the tendon-bone boundary. New tendinous tissue must also form to replace that which has been incorporated in bone.

The metal marker experiments indicated that the zone of most rapid tendon growth is in the insertion area, close to the tendon-bone boundary. However, it is not possible to determine the zone exactly with this technique. Fig. 2 shows that two days after the administration of the ^{35}S-sulphate the bone at the insertion area displayed a very narrow radioactive zone which remained in the bone. When 8—13 days had elapsed from the administration of the isotope, a relatively narrow, more weakly radioactive zone, clearly distinguished from the

stronger radioactivity of the environment, could be seen on the tendon-bone boundary.

These results may be explained as follows: the rate at which tendinous tissue is produced in the insertion area is not the same in all parts of the area, but there is a zone in which the connective tissue is synthesized more rapidly than elsewhere in the environment. Part of the connective tissue formed at the time of administration of ^{35}S-sulphate is incorporated in the bone and, following this, new connective tissue is laid down, especially in the zone of most rapid growth, which is not radioactive. Another possible explanation is that the radioactive connective tissue is in soluble form along the tendon-bone boundary and the pale zone is thus an artefact. However, the results using ^{3}H-thymidine show that there are zones in the insertion region which have varying population kinetics, although the boundaries between them are not sharp. Relatively few mitoses take place in zone c compared with the adjoining zones. It is thus possible that on moving from area *b* to area c cellular proliferation diminishes and synthesis of the intracellular substance increases. Hence, the insertion area can be compared functionally with the epiphyseal plate in which it is possible to distinguish between, e.g., a cell proliferation layer and a layer of mature cells which synthesize the intercellular substance.

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SUMMARY

The aim of the present study was to elucidate the displacement of the sites of insertion of tendons and ligaments in regard to the central part of diaphysis during growth of tubular bones. The problem was studied using ^{35}S-sulphate and autoradiographic technique; tetracycline technique and metal markers fixed to tendons, ligaments and bone; ^{3}H-thymidine and stripping film autoradiographic technique. A total of 144 growing rabbits and additional control animals were used for the experiments.

Two different processes were noted as occurring simultaneously in the region of insertion during growth: longitudinal growth of tendon or ligament in the insertion area which is proportional to epiphyseal growth; and direct incorporation of newly-formed tendinous tissue in osseous tissue.

According to these events, the sites of insertion of tendons and ligaments in long tubular bones remain relatively unchanged topographically despite bone growth.

REFERENCES

Amprino, R (1955) Autoradiographic research on the ^{35}S-sulphate metabolism in cartilage and bone differentiation and growth *Acta anat* 24, 121—163

Biermann, H (1957) Die Knochenbildung im Bereich periostaler-diaphysarer Sehnen- und Bandansatze *Z Zellforsch* 46, 635—671.

Brondolo, W. & Randelli, G (1962) La distribuzione del radioisotopo S^{35} nelle ossa lunghe di ratti albini *Arch Ortop* 75, 1414—1426

Crane, W A J (1962) Sites of mucopolysaccharide synthesis in the lesions of experimental hypertension in rats *J Path Bact* 83, 183—193.

Crawford, G N C (1950) An experimental study of tendon growth in the rabbit. *J Bone Jt Surg* 32 B, 234—243

Crawford, G N C (1954) An experimental study of muscle growth in the rabbit *J Bone Jt Surg* 46 B, 294—303

Dziewiatkowski, D D (1949) Rate of excretion of radioactive sulfur and concentration in some tissues of the rat after intraperitoneal administration of labelled sodium sulfate *J Biol Chem* 178, 197—202

Dziewiatkowski, D D (1951) Radioautographic visualization of sulfur-35 disposition in the articular cartilage and bone of suckling rats following injection of labelled sodium sulfate *J exp Med* 93, 451—456

Dziewiatkowski, D D (1962) Intracellular synthesis of chondroitin sulfate *J. Cell Biol* 13, 359—364

Engfeldt, B & Westerborn, O (1960) An autoradiographic study of the epiphyseal cartilage in normal rabbits after administration of radiosulphate *Acta path. microbiol scand* 49, 73—81

Ham, A W (1965) Histology, 5th ed, Pitman Medical Publishing Company, London

Hughes, H (1956) An experimental study of the post-natal growth of tendon. *Anat Anz* 103, 192—197

Ibsen, K H & Urist, M R (1962) Complexes of calcium and magnesium with oxytetracycline *Proc Soc exp Biol* 109, 797—801

Jackson, S (1953) Chondroitin sulphuric acid as a factor in the stability of tendon *Biochem J* 54, 638—641

Karakarju, E O (1967) Deformation of vertebrae in experimental scoliosis. The course of bone adaption and modelling in scoliosis with reference to the normal growth of the vertebra *Acta orthop scand suppl* 105

Langenskiold, A, Rytomaa, T & Videman, T (1967) An autoradiographic study with ^{35}S-sulphate on the growth in diameter of epiphyseal cartilage in rabbits *Acta orthop scand suppl* 106

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Langenskiöld, A. & Videman, T. (1967) Tillvaxtmekanismen i senor (
Paper presented at the meeting of Finska Läkaresällskapet o
1967, in Helsinki.

Mancini, R. E., Vilar, O., Stein, E. & Fiorini, H. (1961) A Histo
radioautoraphic study of the participation of fibroblasts in t
of mucopolysaccharides in connective tissue. *J. Histochem*
278—291.

Milch, R. A., Rall, D. P. & Tobie, J. E. (1957) Bone localization of th
J. nat. Cancer Inst. 19, 87—91.

Puranen, J. (1966) Reorganization of fresh and preserved bone
experimental study in rabbits using tetracycline labellir
scand. suppl. 92.

Saltzman, A. (1950) Fluorphotometric estimation of Aureomy
urine. *J. Lab. clin. Med. 35,* 123—128.

Schneider, H. (1956) Zur Struktur der Sehnenansatzzonen, Z
Gesch. 119, 431—456.

Warwick, W. T. & Wiles, P. (1934) The growth of periosteum
J. Surg. 22, 169—174.

Carl Zeiss Oberkochen/Württ. (1962) Integrationsokular I.

Langenskiold, A. & Videman, T. (1967) Tillväx'
Paper presented at the meeting of Finsl
1967, in Helsinki.
Mancini, R. E., Vilar, O., Stein, E. & Fior
radioautoraphic study of the participat
of mucopolysaccharides in connective
278—291.
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experimental study in rabbits usi
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urine. *J. Lab. clin. Med.* 35, 123—
Schneider, H. (1956) Zur Struktur d(
Gesch. 119, 431—456.
Warwick, W. T. & Wiles, P. (1934) Tl
J. Surg. 22, 169—174.
Carl Zeiss Oberkochen/Württ. (1962)

Langenskiöld, A. & Videman, T. (1967) Tillväxtmekanismen i senor och ligament. Paper presented at the meeting of Finska Läkaresällskapet on October 5. 1967, in Helsinki.

Mancini, R. E., Vilar, O., Stein, E. & Fiorini, H. (1961) A Histochemical and radioautoraphic study of the participation of fibroblasts in the production of mucopolysaccharides in connective tissue. *J. Histochem. Cytochem. 9,* 278—291.

Milch, R. A., Rall, D. P. & Tobie, J. E. (1957) Bone localization of the tetracyclines. *J. nat. Cancer Inst. 19,* 87—91.

Puranen, J. (1966) Reorganization of fresh and preserved bone transplants. An experimental study in rabbits using tetracycline labelling. *Acta orthop. scand. suppl. 92.*

Saltzman, A. (1950) Fluorphotometric estimation of Aureomycin in blood and urine. *J. Lab. clin. Med. 35,* 123—128.

Schneider, H. (1956) Zur Struktur der Sehnenansatzzonen, Z. *Anat. Entwickl.-Gesch. 119,* 431—456.

Warwick, W. T. & Wiles, P. (1934) The growth of periosteum in long bones *Brit J. Surg 22,* 169—174.

Carl Zeiss Oberkochen/Württ. (1962) Integrationsokular I.